

DIGITAL SIMULATION OF A
TRANSPORTATION INTERFACE

by

CHRYSSOSTOMOS CHRYSSOSTOMIDIS

B.Sc., University of Durham
(1965)

S.M., Massachusetts Institute of Technology
(1967)

Nav. Arch., Massachusetts Institute of Technology
(1968)

SUBMITTED IN PARTIAL FULFILLMENT

OF THE REQUIREMENTS FOR THE

DEGREE OF DOCTOR OF

PHILOSOPHY

at the

MASSACHUSETTS INSTITUTE OF

TECHNOLOGY

February, 1970

Signature of Author _____
Department of Naval Architecture and
Marine Engineering, January 8, 1970

Certified by _____ Thesis Supervisor

Accepted by _____
Chairman, Departmental Committee
on Graduate Students



by
CHRYSSOSTOMOS CHRYSSOSTOMIDIS

Submitted to the Department of Naval Architecture and Marine Engineering on January 8, 1970, in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

ABSTRACT

In this study, two basic tasks have been considered.

The first of these was the development of the mathematical model simulating a cargo transportation interface in which the cargo is to be transported from a ship moored at some distance from the shore to point A on a beach where no port facilities are available. The transferring of cargo from the ship to the shore is accomplished by means of transfer vehicles, such as amphibious craft. The cargo transfer from the ship to the transfer vehicles is accomplished by ship-based unloading gear, such as ship-based cranes. The cargo transfer from the transfer vehicles at the shore is accomplished by beach-based unloading gear, such as fork lifts.

The second of these was the selection of the solution method that would permit the analysis of such a mathematical model. Importance was attached to the condition that the solution method should enable the user to gain an insight into the unloading procedure and thence to correctly derive the optimum use strategies in the ship-to-shore transfer analysis. The method chosen was that of computer digital simulation because it not only provides the user with the necessary insight, but also allows the user to solve the problem at hand without the need for the introduction of drastic simplifications into the mathematical model, as would certainly be required by any of the known optimization techniques. As a further means of enhancing the usefulness of our methodology, the concept of antithetic variance was introduced into our solution procedure. (Antithetic variance is the means by which the user may exercise the underlying [stochastic] mathematical model the minimum number of times in order to estimate the necessary results with a prespecified degree of confidence.)

Because digital simulation is employed as the solution method in almost all congestion problems, it follows that antithetic variance may also be used profitably in models other than the one in this study. Guidelines for the user have therefore been included, wherein the expected usefulness of the concept of antithetic variance (as developed here) in its application to congestion problems in general is indicated.

Thesis Supervisor: Ernst G. Frankel

Title: Professor of Naval Architecture and Marine Engineering

Acknowledgments

The research reported in this study was carried out under the sponsorship of the Office of Naval Research under M.I.T. DSR No. 70562. The author is grateful to the Office of Naval Research for their interest in this subject and for their financial support.

The author also wishes to thank Professors E. G. Frankel, J. W. Devanney III, J. M. Sussman, and P. Mandel of M.I.T. for their continuous encouragement and constructive ideas at all phases of this study. Finally, the author is indebted to his wife, Margie, for editing and proofreading the final draft, to Mrs. V. Liddell for her excellent typing of the final draft, and to Miss L. Carella and Miss B. Leblanc for helping out with the typing when the deadline was drawing close.

All computations were performed at the Computation Center of the Massachusetts Institute of Technology.

Table of Contents

	<u>Page</u>
ABSTRACT	2
ACKNOWLEDGMENTS	3
LIST OF TABLES	5
LIST OF FIGURES	6
1. INTRODUCTION	7
2. SOLUTION PROCESS	10
3. PROBLEM DEFINITION	20
4. FORMULATION OF THE MATHEMATICAL MODEL	61
5. SOLUTION METHOD	100
A. Event Definition	100
B. Scheduling Mechanism Definition	102
C. Computer Program Description	105
D. General Flow Chart	112
E. Concept of Antithetic Variance	115
6. PROBLEM SOLUTION	168
7. EVALUATION OF RESULTS, CONCLUSIONS, AND FUTURE RECOMMENDATIONS	192
BIBLIOGRAPHY	198
APPENDIX A - Additional Information Pertaining to the Solution Method	201
APPENDIX B - Input Data Listing	215
APPENDIX C - Computer Program Listing	224
BIOGRAPHICAL NOTE	307

List of Tables

<u>Table No.</u>		<u>Page</u>
3-1	Processes Describing Breakdown Considerations	37
6-1	Experimental Data for the Digital Simulation of a Transportation Interface Test Cases	170
6-2	Mother Ship's Closure Time	171
6-3	Beach Unloading Facilities' Closure Time	172
6-4	Transfer Vehicle Closure Time	173
A-6	Input Data for the Experiment Leading to Figs. 5-3 and 5-4	214

List of Figures

<u>No.</u>		<u>Page</u>
2-1	Block Diagram of Solution Processes	11
3-1	General Model Construction	21
5-1a	General Flow Chart	112
5-1	1Q-1S System Mean Customer Waiting Time (η vs σ_L^2 & σ_S^2) .	137
5-2	" " " " " " (η vs ρ)	138
5-3	" " " " " " for $\rho=0.90$ (η vs σ_L^2 & σ_S^2)	140
5-4	" " Mean of Mean Customer Waiting Time vs. Variance	141
5-5	" " Mean Time that the Server Remained Idle (η vs σ_L^2 & σ_S^2)	150
5-6	" " Mean Time that the Server Remained Idle for $\rho=0.90$ (η vs σ_L^2 & σ_S^2)	151
5-7	" " Mean Time to Serve 200 Customers (η vs σ_L^2 & σ_S^2)	159
5-8	" " Mean Time to Serve 200 Customers for $\rho=0.90$ (η vs σ_L^2 & σ_S^2)	160
6-1	General Data Setup	174
6-2	Input Data Setup for the j_1 th Case	175
6-3	" " " " " Payload Description	176
6-4	" " " " " T.V.'s Payload Characteristics	177
6-5	" " " " " Time Characteristics.....	178
6-6	" " " " " S.U.F.'s Time Characteristics.	179
6-7	" " " " " B.U.F.'s " " .	180
6-8	" " " " " T.V.'s " " .	181
6-9	" " " " " Indication of the Stochastic Behavior of the j_1 th Case...	182
6-10	" " " " " Indication of the Stochastic Behavior of the S.U.F.....	183
6-11	" " " " " Indication of the Stochastic Behavior of the B.U.F.....	184
6-12	" " " " " Indication of the Stochastic Behavior of the T.V.....	185
6-13	" " " " " Description of the Stochastic Behavior of the j_1 th Case...	186
6-14	" " " " " Description of the Stochastic Behavior of the S.U.F.....	187
6-15	" " " " " Description of the Stochastic Behavior of the B.U.F.....	188
6-16	" " " " " Description of the Stochastic Behavior of the T.V.....	189
6-17	" " " " " Description of the T.V.'s Breakdown Characteristics...	190
6-18	Input Data Setup for STATIC.....	191
7-1	Weight (\bar{W}) and Volume (\bar{V}) Utility of Transfer Vehicles...	196

The basic task of the problem posed is that of developing the methodology that will permit the overall analysis of a cargo offloading procedure. In the offloading procedure under investigation, the cargo is to be unloaded from a ship, henceforth referred to as the mother ship, which is at some distance, say x miles, from the shore. The Mother Ship is to be stationary during the entire unloading operation. The final and only destination of the cargo is to be a point A on the beach. There are to be no port facilities on the shore or beach unloading areas.

The cargo involved in this study is to be contained in

- i) Containers or pallets of arbitrary size, weight and capacity that are not capable of any self-induced motion, or
- ii) Vehicles of arbitrary size, weight and capacity that are capable of self-induced rolling motion only. It should be noted that in this case the vehicle itself may be the cargo.

The actual transferring from the Mother Ship to the beach is to be accomplished by means of amphibious craft, whose number and characteristics have been prespecified. These are henceforth referred to as the transfer vehicles, such as LARCs, GEMs, etc. The loading into the transfer vehicles alongside the mother ship is to be in one of the two

modes: sequential or simultaneous. Similarly, but totally independent from the loading mode, the unloading from the transfer vehicles on the beach is to be in one of the two modes: sequential or simultaneous.

In order to accomplish the cargo transfer from the Mother Ship to the transfer vehicles, the Mother Ship is to be provided with all the necessary unloading facilities, for example ship-borne crane(s), ramp(s), etc. However, the transfer vehicles are not to be provided with any special unloading facilities, because some means, such as a fork lift, is to be made available on the beach to carry out the cargo unloading.

Finally, the prespecified number of transfer vehicles and beach unloading gear is to be made available at point A, and their transportation and arrival is to be independent of that of the Mother Ship, and from each other.

With the above description, the cargo offloading procedure under investigation has been fully defined. In order to complete the description of the problem posed, it remains to define the analysis objectives, which can be stated as follows: The resulting technique is to be designed to first provide a common measure of success for a number of prespecified use strategies for given ship-based loading facilities, transfer vehicles and beach-based unloading facilities distributions, for a given x and environment state, and for given breakdown considerations. The common measure

of success is to depend on time and/or the number of transfer vehicles malfunctioning. Thus the final analysis objective is to determine the best strategy (with respect to the measure of success mentioned above) among those examined or, if the findings of the previous calculations suggest it, to continue the analysis with new strategies until the desired one is found. It should be noted that in selecting the measure of success mentioned above the author was limited by the requirements of the sponsor.

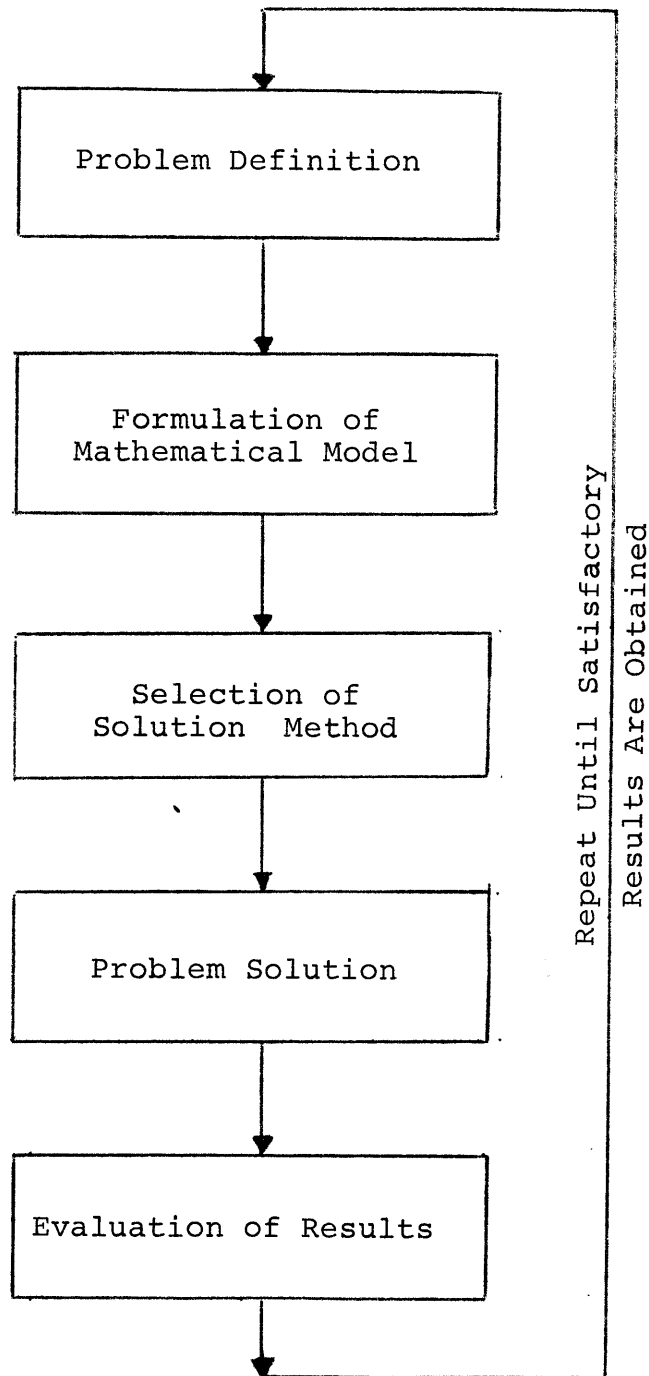
With the above, the problem description has been completed. The solution process is to be outlined in the subsequent Sections and Appendices. We start our discussion with a general outline of the solution process.

The solution process in this study is best illustrated by the block diagram shown in Fig. 2-1. A brief discussion of each step involved in the solution process is given below.

Problem Definition. This involved the following:

- i) Identification of the variables of the problem.
- ii) Establishment of the relations among the variables.
- iii) Identification of the dependent and independent variables of the problem consistent with i) and ii).
- iv) Establishment of the range of variation of all problem parameters.
- v) Selection of the figure of merit.
- vi) Choice of Use Strategies.

By definition, the variables of a problem are those parameters necessary to fully describe a given system to the degree of accuracy and extent desired. The process of variable identification for a new problem, such as ours, is a major and a very difficult task. In order to simplify our task of identifying our variables, it was found advantageous to first identify the subsystems involved in our study and then find the variables necessary to fully describe each subsystem to the degree of accuracy and extent desired. The subsystems involved in our study were found to be:



BLOCK DIAGRAM OF SOLUTION PROCESS

Fig. 2-1

1. The mother ship.
2. The payload.
3. The ship-based unloading facilities, S.U.F.
4. The shore-based unloading facilities, B.U.F.
5. The transfer vehicles, T.V.

The variable identification is deferred until the next Section where the Problem Definition will be discussed in detail. It is of importance to note in conjunction with the discussion of the variable identification that although it was recognized that the environment state as described by

1. Wind speed,
2. Sea state,
3. Current,
4. Tide,
5. Obstacles,
6. Beach configuration, and
7. Shore configuration

influences our offloading operation, it was decided to describe their effect by externally adjusting the magnitude of the appropriate parameters. For this reason, it is not necessary to identify any variables that describe the environment state. However, when assigning the magnitude of the parameters that are affected by the environment state, the user must assign the appropriate values by taking the environment state into consideration.

The establishment of the relations, if any, among the problem variables is a necessity as they form a part of the mathematical model. The reason for this is that because the mathematical model is, by definition, the replica of our system in the form of mathematical equations, any such relations must be part of it in order to permit it to be a true replica of the original. The establishment of any such relations is deferred until the next Section where the Problem Definition will be discussed in detail.

As was stated at the beginning of this section, the problem variables were so selected that when the appropriate values were assigned to them, they could serve to define a given offloading system uniquely to the degree of accuracy and extent desired. This, however, should not be taken to imply that if we assign arbitrary but logical values to these variables we will always be able to generate an offloading system because of the possible interrelations among the variables, which do not permit independent selection of values for all the interrelated variables. This fact makes it necessary to identify those variables whose values can be assigned arbitrarily and those whose value cannot. This is because our solution method involves the evaluation of different offloading systems which are generated by prespecifying the values of their variables. This is best done by classifying the variables into dependent and independent ones. The independent variables are those variables which must be prescribed to

completely describe our system as desired. The dependent variables are the ones remaining in our original list of variables after the independent ones have been removed. The identification of the dependent and independent variables is deferred until the next Section where the Problem Definition will be discussed in detail.

Ideally speaking, we would like to impose no restrictions on the range of variation of our problem parameters, other than the ones implied by the physics of our problem, as this will tend to decrease the universality of our methodology. However, there are practical considerations, common to this type of problem, which make it necessary that we impose limits on the range of variation of our problem parameters. The most common of these considerations (requiring us to compromise by imposing limits on the range of variation of our problem parameters) is that it is impossible to construct the mathematical model valid over the entire range of variation of the problem parameters. In the few times that it is possible to construct such a model, it again becomes necessary to restrict the range of variation to simplify the model and make it a useful engineering tool. Therefore, the above indicates the need for the introduction of restrictions as unavoidable. These restrictions, of course, ought to be introduced with great care. Care should be taken because we do not wish to reduce the universality of our methodology unnecessarily, as

we wish to utilize it to solve most, if not all, of the problems that we are likely to encounter, but at the same time we wish to obtain this solution with relative ease and consistent but adequate precision. The introduction of these restrictions is deferred until the next section, when the Problem Definition will be discussed in detail.

As was already mentioned in the Introduction, the figure of merit (the measure of success) is the weighted combination of time and the number of transfer vehicles malfunctioning. The time component of the figure of merit involves the calculation of mean time elapsed since the start of the mission to

1. prepare the mother ship for departure after all the payload has been transferred into the transfer vehicles, and all transfer vehicles have cleared the mother ship,
2. complete the payload transfer from the mother ship to point A on the beach,
3. return all transfer vehicles to their bases, and
4. return all beach-based unloading facilities to their bases.

The latter component of the figure of merit involves the calculation of the percentage of transfer vehicles that did not complete their mission because of breakdown. The factors determining the likelihood of breakdown for each transfer vehicle are:

1. Reliability of the transfer vehicle's components.
2. Hazard vulnerability.
3. Control stability.
4. Operational limitations.

The establishment of the exact nature of the figure of merit is deferred until the next Section where the Problem Definition will be discussed in detail.

Finally, the set of use strategies to be incorporated in the mathematical model of this study were developed. Although it is anticipated that for all cases likely to be encountered in practice, the best strategies may be found among those incorporated into our model, the algorithm is to be made sufficiently flexible to allow the introduction of more use strategies for the investigation of cases not predicted here. The description of the use strategies to be incorporated into our mathematical model is deferred until the fourth section where the mathematical model of our study will be developed.

Formulation of the Mathematical Model.

As was stated earlier, the mathematical model is, by definition, the replica of our system, to the degree of accuracy and extent desired, in the form of mathematical equations. Because of the nature of our problem, the mathematical model is stochastic in nature. In setting up the mathematical model care was taken to keep it as simple as possible to permit easy analysis, and yet to construct it so that it exhibits all the

phenomena under consideration, as required. The actual construction of the mathematical model is deferred until the fourth section.

Selection of Solution Method.

From the Problem Definition one may easily observe that the easiest way to achieve the desired goal, namely, to find the best use strategy, is to treat the use strategy as a problem variable, and then solve the problem under investigation as an optimization problem. The resulting optimization problem is a mixed integer one, or simply an integer problem if the waiting times of the transfer vehicles and unloading facilities are approximated by integers. However, it was soon discovered that in order to solve the problem as an optimization one, drastic simplifications had to be made to the mathematical model to allow us to efficiently implement the solution in present-day computers. The reason for this is that the state description of our system was large. The drastic simplifications necessary made our methodology a very inefficient engineering tool. Last, but not least, if the use strategy obtained by solving the problem as an optimization one was very complicated, it probably would have been very difficult to implement in practice (because the system might be operating under external pressure). For this reason it would be very easy to violate a complicated optimum use strategy and to actually adopt a suboptimal solution whose merit

cannot be estimated in any way, which is a very undesirable situation as it defeats the purpose of this analysis.

For the reasons given above it was decided to develop a methodology that will yield the desired solution, not necessarily as directly as it would have been provided by the optimization theory, but one which

1. could be implemented without requiring major simplifications in the mathematical model, and
2. could test logical and likely "optimal" use strategies which have a very high probability of being implemented in practice.

The method that satisfied all the above requirements was the digital simulation method, which was utilized in this study to obtain the desired solution. By this method the desired solution was obtained by testing different use strategies that satisfied the second requirement given above. To develop these use strategies, one is guided by logic, especially in developing the first use strategy to be tested, and by the insight gained from the previous tries when this is available. The discussion of the actual details of the methodology used in this study is deferred until the fifth section.

Problem Solution

This involves the preparation of the input required by the computer program. Special care must be taken when preparing the input of the parameters, whose magnitude is affected by environment state and breakdown considerations. Further discussion on this topic is deferred until later.

Evaluation of Results

With reference to Fig. 2-1, special care was taken that the only iteration required in the Solution Process is the preparation of new input data for the examination of a new use strategy, if the Evaluation of Results suggests it. It is anticipated that there will never be any need for the alteration of the first three steps of Fig. 2-1, as care was taken to make the methodology developed here general, in order to handle all cases likely to be encountered in practice. However, if a case arises where a change must be introduced in these three steps, the user must read very carefully the next three sections so that he may correctly alter the present method to suit his needs. Further discussion on this topic is deferred until later.

The above completes the introduction in the Solution Process. In the next section a detailed presentation of the Problem Definition will be given.

3. Problem Definition

In this section a detailed discussion of each step involved in the Problem Definition is given.

i) Identification of the Problem Variables

In view of the fact that the smaller the number of variables in a problem the more economical, and in many instances the more efficient, the solution process becomes, an attempt was made to keep the number of variables of this problem to a minimum. To do so it was necessary to introduce certain assumptions. However, special care was taken so that the nature and number of these assumptions was such as not to diminish the generality of our methodology. These assumptions will be enumerated in the fourth topic of this section, when the range of variation of the problem parameters is discussed.

As was mentioned earlier, in order to simplify our task of identifying our problem variables, the subsystems involved in our study were identified. These are shown diagrammatically in Fig. 3-1. For presentation purposes, the variables that are utilized to define each subsystem and at the same time appear in the computer input will be listed first, while the remaining variables necessary to complete each subsystem's description will be given later.

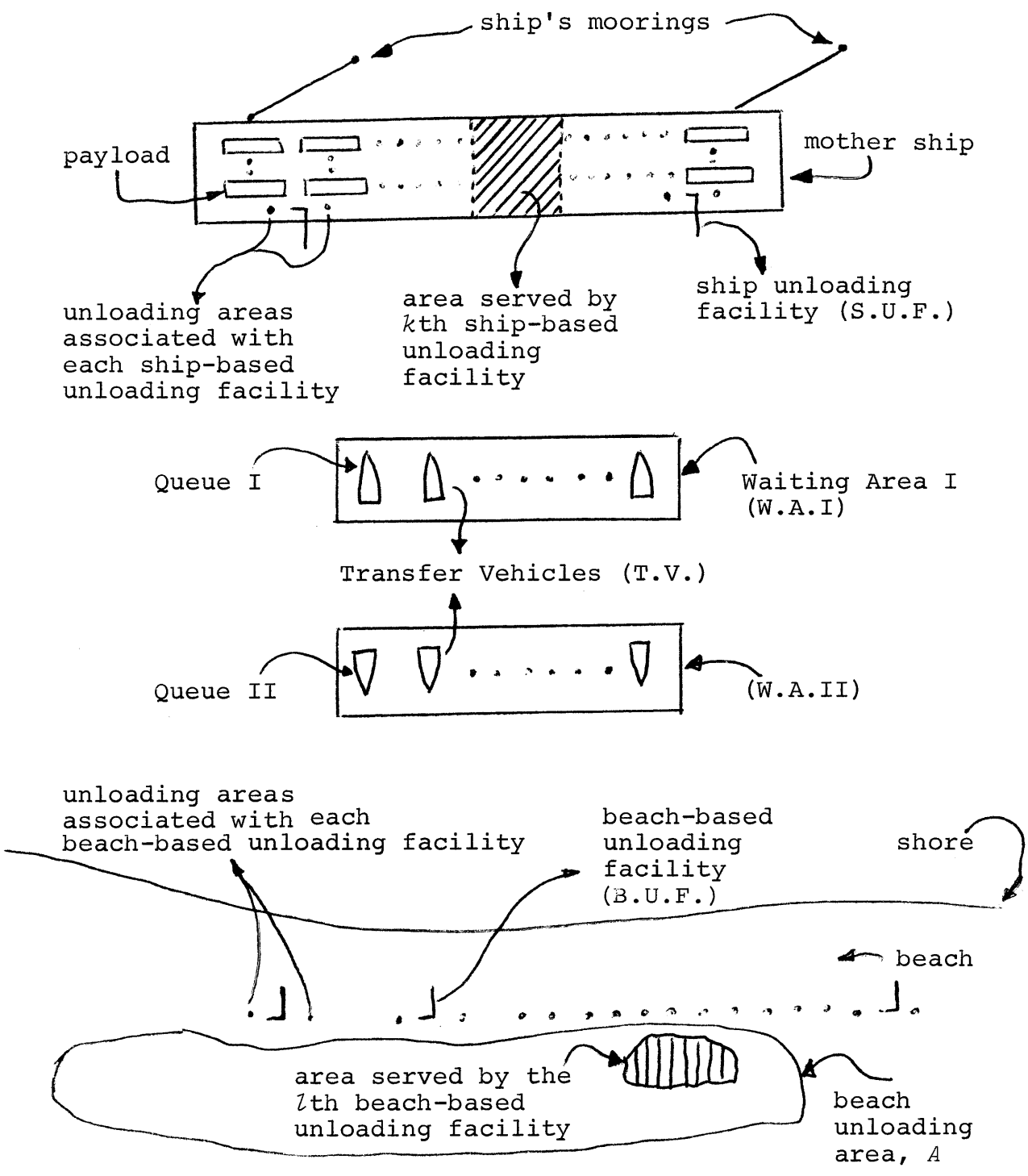


Fig. 3-1 GENERAL MODEL CONSTRUCTION

MOTHER SHIP DESCRIPTION

The variables* selected to describe the Mother Ship's performance are:

TAM giving the number of units of time after the start of the mission that the Mother Ship is expected to arrive in the theater of operations [$-999 \leq TAM \leq 9999$ (treated as a floating point number)].

T1 giving the number of units of time required to complete the mooring operations of the Mother Ship after it arrived in the theater of operations [$0. < T1 \leq 9999$ (treated as a floating point number)].

T2 giving the number of units of time required to free the Mother Ship from its moorings and make ready to travel after all S.U.F. are secured to position and all T.V. have cleared the Mother Ship [$0. < T2 \leq 9999$ (treated as a floating point number)].

*IDMA*** indicating the nature of the process concerning the arrival of the Mother Ship.

*ID1*** indicating the nature of the process concerning the mooring operation of the Mother Ship.

*ID2*** indicating the nature of the process concerning the operation of freeing the Mother Ship from its moorings.

*The magnitude of all the variables selected to describe the Mother Ship's performance except the magnitude of *INMS*, *IN1*, *IN2* and *TIME* is affected by environmental state.

***IDMA*, *ID1*, *ID2* = 1 if the process is deterministic.
 = 2 if the process is stochastic, drawn from $U(0,1)$ distribution.
 = 3, 4...9999 if the process is stochastic, drawn from distributions to be developed by the user, if so desired.

- INMS* giving the seed of the $U(0,1)$ distribution, which serves to predict the stochastic behavior of the Mother Ship's arrival process, if $IDMA = 2^{***}$ [$1 \leq INMS \leq 10^9 - 1$].
- AMINM* giving the minimum value of the range of variation of *TAM*, if $IDMA = 2^{***}$ [$-999.99999 \leq AMINM < 9999.99999$].
- AMAXM* giving the maximum value of the range of variation of *TAM*, if $IDMA = 2^{***}$ [$-999.99999 < AMAXM \leq 9999.99999$].
- IN1* giving the seed of the $U(0,1)$ distribution, which serves to predict the stochastic behavior of the Mother Ship's mooring operation, if $ID1 = 2^*$ [$1 \leq IN1 \leq 10^9 - 1$].
- AMIN1* giving the minimum value of the range of variation of *T1* if $ID1 = 2^*$ [$0. < AMIN1 < 9999.99999$]
- AMAX1* giving the maximum value of the range of variation of *T1* if $ID1 = 2^*$ [$0. < AMAX1 \leq 9999.99999$].
- IN2* giving the seed of the $U(0,1)$ distribution, which serves to predict the stochastic behavior of the operation of freeing the Mother Ship from its moorings, if $ID2 = 2^{**}$ [$1 \leq ID2 \leq 10^9 - 1$].
- AMIN2* giving the minimum value of the range of variation of *T2* if $ID2 = 2^{**}$ [$0. < AMIN2 < 9999.99999$].
- AMAX2* giving the maximum value of the range of variation of *T2* if $ID2 = 2^{**}$ [$0. < AMAX2 \leq 9999.99999$].
- TIME* giving the units of time utilized in this study [$0 \leq TIME \leq 12$ alpha numeric characters].

*If $ID1=1$ *IN1*, *AMIN1* and *AMAX1* are not problem variables.
 **If $ID2=1$ *IN2*, *AMIN2* and *AMAX2* are not problem variables.
 ***If $IDMA=1$ *INMS*, *AMINM* and *AMAXM* are not problem variables.

PAYLOAD DESCRIPTION

The variables selected to describe the payload are:

N_k giving the number of payload units to be unloaded by each of the k ($k = 1, 2, \dots, K$) S.U.F.

$$\left(1 \leq N_k \leq 1000 \text{ and } \sum_{k=1}^K N_k \leq 1000 \right).$$

WC_n giving the weight of each of the n $\left(n = 1, 2, \dots, \sum_{k=1}^K N_k \right)$ payload units plus that of their lashings $[0.<WC_n \leq 99.99]$.

VC_n giving the volume of each of the n $\left(n = 1, 2, \dots, \sum_{k=1}^K N_k \right)$ payload units together with that of their lashings* $[0.<VC_n \leq 9999 \text{ (treated as a floating point number)}]$.

$WGHT$ giving the units of weight utilized in this study $[0 \leq WGHT \leq 12 \text{ alpha numeric characters}]$.

VOL giving the units of volume utilized in this study $[0 \leq VOL \leq 12 \text{ alpha numeric characters}]$.

*If all the T.V. employed in this study do not permit vertical stowing of the payload, VC_n can be utilized to give the volume per unit height plus the surface area required by their lashings rather than the volume of each of the n ($n=1, 2, \dots, \sum_{k=1}^K N_k$) payload units and that of their lashings, as this is a quantity much easier to estimate.

The variables* selected to describe the S.U.F.'s performance are:

- K giving the number of S.U.F.** involved in this case [$1 \leq K \leq 20$].
- $ISUD$ *** indicating the nature of the unloading mode at the Mother Ship.
- $ISCSL$ **** indicating which of the S.U.F. use strategies is to be used.
- $TSC_{1,k}$ giving the time required for the k th ($k = 1, 2, \dots, K$) S.U.F. to be made ready to start the unloading operation and reach the k th ship unloading area after the Mother Ship is properly moored [$0. < TSC_{1,k} \leq 9999$ (treated as a floating point number)].

* The magnitude of all the variables selected to describe the S.U.F.'s performance except the magnitude of $INSC_{j_2,k}$ ($j_2 = 1, 2, \dots, 5, 7, 8, 9; k = 1, 2, \dots, K$) is affected by the environment state.

** Each S.U.F. is identified by a distinct number, k , such that $1 \leq k \leq K$.

*** $ISUD = 1$ if the unloading mode at the Mother Ship is to be in parallel. $ISUD = 2$ if the unloading mode at the Mother Ship is to be sequential.

**** If $ISCSL = 1$, S.U.F. use strategy $SLSCA$ is used to select the appropriate S.U.F. when necessary.
 = 2, S.U.F. use strategy $SLSCB$ is used to select the appropriate S.U.F. when necessary.
 = 3, S.U.F. use strategy $SLSCC$ is used to select the appropriate S.U.F. when necessary.
 = 4, 5...9, additional S.U.F. use strategies to be developed by the user, if desired, for selecting the appropriate S.U.F. when necessary.

- $TSC_{2,k}$ giving the time required for the k th ($k = 1, 2 \dots K$) S.U.F. to travel to any of the N_k payload units from the k th ship unloading area [$0. < TSC_{2,k} \leq 9999$ (treated as a floating point number)].
- $TSC_{3,k}$ giving the time required to release any of the N_k ($k = 1, 2 \dots K$) payload units after the k th S.U.F. has reached the payload unit in question [$0. < TSC_{3,k} \leq 9999$ (treated as a floating point number)].
- $TSC_{4,k}$ giving the time required to secure any of the N_k ($k = 1, 2 \dots K$) payload units on the k th S.U.F. after the payload unit in question has been released [$0. < TSC_{4,k} \leq 9999$ (treated as a floating point number)].
- $TSC_{5,k}$ giving the time required to transport any of the N_k ($k = 1, 2 \dots K$) payload units to the k th ship unloading area after the payload unit in question has been secured on the S.U.F. [$0. < TSC_{6,k} \leq 9999$ (treated as a floating point number)].
- $TSC_{7,k}$ giving the time required to unload and then free any of the N_k ($k = 1, 2 \dots K$) payload units from the k th S.U.F. and to then make the k th S.U.F. ready to travel again. This operation is performed only if (a) the appropriate T.V. is properly secured in the k th ship unloading area and has completed its refueling (if refueling was necessary), (b) the previous payload unit unloaded by the S.U.F. in question is fully secured in the T.V. in question (this requirement is void if the payload unit in question is the first payload unit to be unloaded in any of the T.V.'s trips), and (c) the T.V.'s remaining capacity can accept the payload unit in question. If any of the above is not satisfied, the k th S.U.F. must wait

- $TSC_{7,k}$ until all three requirements are satisfied
(cont'd.) [$0. < TSC_{7,k} \leq 9999$ (treated as a floating point number)].
- $TSC_{8,k}$ giving the time required for the k th ($k = 1, 2 \dots K$) S.U.F. to travel back to its original position from the k th ship unloading area after the last of the N_k payload units has been transferred onto the appropriate T.V. [$0. < TSC_{8,k} \leq 9999$ (treated as a floating point number)].
- $TSC_{9,k}$ giving the time required for the k th ($k = 1, 2 \dots K$) S.U.F. to be secured to its original position.
- $IDSC_{j_2,k}^*$ indicating the nature of each of the j_2 ($j_2 = 1, 2 \dots \dots 5, 7, 8, 9$) processes described above for each of the k ($k = 1, 2 \dots K$) S.U.F.
- $INSC_{j_2,k}$ giving the seed of the $U(0,1)$ distribution, which serves to predict the stochastic behavior of each of the j_2 ($j_2 = 1, 2 \dots 5, 7, 8, 9$) processes described above for each k ($k = 1, 2 \dots K$), if $IDSC_{j_2,k} = 2^{**}$
[$1 \leq INSC_{j_2,k} \leq 10^9 - 1$].
- $AMINSC_{j_2,k}$ giving the minimum value of the range of variation of $TSC_{j_2,k}$ ($j_2 = 1, 2 \dots 5, 7, 8, 9; k = 1, 2 \dots K$), if $IDSC_{j_2,k} = 2^{**}$ [$0. < AMINSC_{j_2,k} < 9999.99999$].
- $AMAXSC_{j_2,k}$ giving the maximum value of the range of variation of $TSC_{j_2,k}$ ($j_2 = 1, 2 \dots 5, 7, 8, 9; k = 1, 2 \dots K$), if $IDSC_{j_2,k} = 2^{**}$ [$0. < AMAXSC_{j_2,k} \leq 9999.99999$].
-
- * $IDSC_{j_2,k} = 1$ if the process is deterministic.
 $= 2$ if the process is stochastic, drawn from $U(0,1)$ distribution.
 $= 3, 4 \dots 9999$ if the process is stochastic, drawn from distributions to be developed by the user, if so desired.
- **If $IDSC_{j_2,k} = 1$ $INSC_{j_2,k}$, $AMINSC_{j_2,k}$ and $AMAXSC_{j_2,k}$ are not problem variables.

B.U.F. DESCRIPTION

The variables* selected to describe the B.U.F.'s performance are:

- L giving the number of B.U.F.** involved in this case [$1 \leq L \leq 20$].
- $IBUD$ *** indicating the nature of the unloading mode at the beach.
- $IBCSL$ **** indicating which of the B.U.F. use strategies is to be used.
- $TBC_{1,\ell}$ giving the number of units of time after the start of the mission that the ℓ th ($\ell = 1, 2, \dots, L$) B.U.F. is expected to depart from its base [$-999 \leq TBC_{1,\ell} \leq 9999$ (treated as a floating point number)].

*The magnitude of all the variables selected to describe the B.U.F.'s performance except the magnitude of

$$INBC_{j_4, \ell} \quad (j_4 = 1, 2, \dots, 4, 6, 7, \dots, 10; \ell = 1, 2, \dots, L)$$

is affected by environment state.

**Each B.U.F. is identified by a distinct number, ℓ , such that $1 \leq \ell \leq L$.

*** $IBUD = 1$ if the unloading mode at the beach is to be in parallel.
 $= 2$ if the unloading mode at the beach is to be sequential.

****If $IBCSL = 1$, B.U.F. use strategy $SLBCA$ is used to select the appropriate B.U.F. when necessary.
 $= 2$, B.U.F. use strategy $SLBCB$ is used to select the appropriate B.U.F. when necessary.
 $= 3, 4, \dots, 9$, additional B.U.F. use strategies to be developed by the user if so desired, for selecting the appropriate B.U.F. when necessary.

- $TBC_{2,\ell}$ giving the time required for the ℓ th ($\ell = 1, 2 \dots L$) B.U.F. to reach point A on the beach from its base [$0. < TBC_{2,\ell} \leq 9999$ (treated as a floating point number)].
- $TBC_{3,\ell}$ giving the time required for the ℓ th ($\ell = 1, 2 \dots L$) B.U.F. to be made ready to start the unloading operation after the ℓ th B.U.F. has arrived at point A on the beach [$0. < TBC_{3,\ell} \leq 9999$ (treated as a floating point number)].
- $TBC_{4,\ell}$ giving the time required for the ℓ th ($\ell = 1, 2 \dots L$) B.U.F. to travel to the ℓ th beach unloading area from point A on the beach after the ℓ th B.U.F. has been made ready to travel [$0. < TBC_{4,\ell} \leq 9999$ (treated as a floating point number)].
- $TBC_{6,\ell}$ giving the time required to release any of the payload units utilizing the ℓ th ($\ell = 1, 2 \dots L$) B.U.F. This operation is performed only if the appropriate T.V. is beached and ready to commence the unloading operation and the ℓ th B.U.F. has reached the ℓ th beach unloading area. If that is not the case, the releasing of the payload unit must wait until the two requirements given above are satisfied [$0. < TBC_{6,\ell} \leq 9999$ (treated as a floating point number)].
- $TBC_{7,\ell}$ giving the time required to secure any of the payload units on the ℓ th ($\ell = 1, 2 \dots L$) B.U.F. after the payload unit has been released [$0. < TBC_{7,\ell} \leq 9999$ (treated as a floating point number)].
- $TBC_{8,\ell}$ giving the time required after the payload unit in question has been secured on the ℓ th ($\ell = 1, 2 \dots L$) B.U.F. to (a) transport any of the payload units from the ℓ th beach unloading area to point A on the beach by utilizing the ℓ th B.U.F., (b) unload and free the

- $TBC_{8,\ell}$ payload unit from the ℓ th B.U.F. and (c) make the (cont'd.) ℓ th B.U.F. ready to travel again [$0. < TBC_{8,\ell} \leq 9999$ (treated as a floating point number)].
- $TBC_{9,\ell}$ giving the time required to prepare the ℓ th ($\ell = 1, 2 \dots L$) B.U.F. for departure after it has terminated its mission [$0. < TBC_{9,\ell} \leq 9999$ (treated as a floating point number)].
- $TBC_{10,\ell}$ giving the time required for the ℓ th ($\ell = 1, 2 \dots L$) B.U.F. to reach its base after it has been made ready for departure [$0. < TBC_{10,\ell} \leq 9999$ (treated as a floating point number)].
- $IDBC_{j_4,\ell}^*$ indicating the nature of each of the j_4 ($j_4 = 1, 2, 3, 4, 6, 7 \dots 10$) processes described above for each of the ℓ ($\ell = 1, 2 \dots L$) B.U.F.
- $INBC_{j_4,\ell}$ giving the seed of the $U(0,1)$ distribution which serves to predict the stochastic behavior of each of the j_4 ($j_4 = 1, 2, 3, 4, 6, 7 \dots 10$) processes described above for each ℓ ($\ell = 1, 2 \dots L$), if $IDBC_{j_4,\ell} = 2^{**}$ [$1 \leq INBC_{j_4,\ell} \leq 10^9 - 1$].
- $AMINBC_{j_4,\ell}$ giving the minimum value of the range of variation of $TBC_{j_4,\ell}$ ($j_4 = 1, 2, 3, 4, 6, 7 \dots 10$; $\ell = 1, 2 \dots L$), if $IDBC_{j_4,\ell} = 2^{**}$ [$-999.99999 \leq AMINBC_{1,\ell} < 9999.99999$; $0. < AMINBC_{j_3,\ell} < 9999.99999$, $j_3 = 2, 3, 4, 6, 7 \dots 10$].
- $AMAXBC_{j_4,\ell}$ giving the maximum value of the range of variation of $TBC_{j_4,\ell}$ ($j_4 = 1, 2, 3, 4, 6, 7 \dots 10$; $\ell = 1, 2 \dots L$), if $IDBC_{j_4,\ell} = 2^{**}$ [$-999.99999 < AMAXBC_{1,\ell} \leq 9999.99999$; $0. < AMINBC_{j_3,\ell} \leq 9999.99999$, $j_3 = 2, 3, 4, 6, 7 \dots 10$].

* $IDBC_{j_4,\ell} = 1$ if the process is deterministic.
 $= 2$ if the process is stochastic, drawn from $U(0,1)$ distribution.
 $= 3, 4 \dots 9999$ if the process is stochastic, drawn from distributions to be developed by the user, if so desired.

**If $IDBC_{j_4,\ell} = 1$, then $INBC_{j_4,\ell}$, $AMINBC_{j_4,\ell}$ and $AMAXBC_{j_4,\ell}$ are not problem variables.

The variables* selected to describe the T.V.'s performance are:

I giving the number of T.V.** involved in this case ($1 \leq I \leq 20$).

*IWA1SL**** indicating which of the T.V. use strategies is to be used in W.A.I.

*IWA2SL***** indicating which of the T.V. use strategies is to be used in W.A.II.

* The magnitude of the variables *IWA1SL*, *IWA2SL*, *ICHANG*, *AMAXTV*_{*j*,*i*} (*i* = 1, 2...*I*), *TTV*_{*j*,*i*} (*j* = 1, 2, 4...7, 9, 10, 11, 13, 15, 16, 17), *IDTV*_{*j*,*i*} (*j* = 1, 2...6, 8, 9, 10...13, 15, 16, 17), *AMINTV*_{*j*,*i*} and *AMAXTV*_{*j*,*i*} is affected by the environment state. The magnitude of the variables *WT1MAX*, *WT2MAX*, *IDBRTV*_{*j*,*i*} (*j* = 1, 2...8) *BRKTV*_{*j*,*i*} is affected by the environment state and breakdown considerations.

** Each T.V. is identified by a distinct number, *i*, such that $1 \leq i \leq I$.

*** If *IWA1SL* = 1, T.V. use strategy *ASLTVA*
 = 2, T.V. use strategy *ASLTVB*
 = 3, T.V. use strategy *ASLTVC*
 = 4, T.V. use strategy *ASLTVD*
 = 5, 6, 7, 8, T.V. use strategy *ASLTVE*
 is used to select the appropriate T.V. from W.A.I when necessary.
 = 9, additional T.V. use strategy to be developed by the user, if so desired, for selecting the appropriate T.V. from W.A.I when necessary.

**** If *IWA2SL* = 1, T.V. use strategy *BSLTVA*
 = 2, T.V. use strategy *BSLTVB*
 = 3, T.V. use strategy *BSLTVC*
 = 4, T.V. use strategy *BSLTVD*
 is used to select the appropriate T.V. from W.A.II when necessary.
 = 5, 6...9, additional T.V. use strategies to be developed by the user, if so desired, for selecting the appropriate T.V. from W.A.II when necessary.

*ICHANG**

T.V. use strategy indicator

32.

*AMAXTV*_{6,i}

giving the weight of payload together with that of the associated lashings that the *i*th (*i* = 1,2...*I*) T.V. can carry in any of its trips [$0. < AMAXTV_{6,i} \leq 9999$ (treated as a floating point number)].

* If *ICHANG* = 1, the T.V. use strategies specified by the user at the outset of the investigation of a case will be used throughout the simulation of the case under investigation.

= 2, the T.V. use strategies specified by the user at the outset of the investigation of a case will be changed automatically with the following rules.

- i) If *IWA1SL* = 1, the instant the weight payload of a T.V. is violated, *IWA1SL* and *IWA2SL* assume the value 2.
- ii) If *IWA1SL* = 3, the instant the weight payload of a T.V. is violated, *IWA1SL* and *IWA2SL* assume the value 4.
- iii) If *IWA1SL* = 2 the instant the volume payload of a T.V. is violated, *IWA1SL* and *IWA2SL* assume the value 1, and
- iv) If *IWA1SL* = 4 the instant the volume payload of a T.V. is violated, *IWA1SL* and *IWA2SL* assume the value 3.

- $AMAXTV_{7,i}$ giving the volume of payload together with that of the associated lashings that the i th ($i = 1, 2 \dots I$) T.V. can carry in any of its trips. Note that the definition of units of $AMAXTV_{7,i}$ must be the same as that of VC_n ($n = 1, 2 \dots \sum_{k=1}^K N_k$) [$0 < AMAXTV_{7,i} \leq 99999$ (treated as a floating point number)].
- $TTV_{1,i}$ giving the number of units of time after the start of the mission that the i th ($i = 1, 2 \dots I$) T.V. is expected to depart from its base [$-999 \leq TTV_{1,i} \leq 9999$ (treated as a floating point number)]
- $TTV_{2,i}$ giving the time required for the i th ($i = 1, 2 \dots I$) T.V. to reach W.A.I from its base [$0. < TTV_{2,i} \leq 9999$ (treated as a floating point number)]
- $TTV_{4,i}$ giving the time required for the i th ($i = 1, 2 \dots I$) T.V. to reach and hook up to any of the ship unloading areas from W.A.I and prepare the i th T.V. for the loading operation. Note that the i th T.V. can leave W.A.I only when there is a ship unloading area free to receive it. [$0. < TTV_{4,i} \leq 9999$ (treated as a floating point number)].
- $TTV_{5,i}$ giving the time required for the i th ($i = 1, 2 \dots I$) T.V. to refuel, when necessary, after it has hooked up at any of the ship unloading areas [$0. < TTV_{5,i} \leq 9999$ (treated as a floating point number)].
- $TTV_{6,i}$ giving the time expected for the i th ($i=1, 2 \dots I$) T.V. will operate at other than zero speed, during a complete cycle. [$0. < TTV_{6,i} \leq 9999$ (treated as a floating point number)].
- $TTV_{7,i}$ giving the time expected that the i th ($i = 1, 2 \dots I$) T.V. will operate at, other than zero speed, without refueling. [$0. < TTV_{7,i} \leq 9999$ (treated as a floating number)]

- $TTV_{9,i}$ giving the time required for any payload unit to be secured on the i th ($i = 1, 2 \dots I$) T.V. after it has been unloaded into the i th T.V. and freed from the appropriate S.U.F., and after the S.U.F. in question has been made ready to travel again [$0. < TTV_{9,i} \leq 9999$ (treated as a floating point number)].
- $TTV_{10,i}$ giving the time required for the i th ($i = 1, 2 \dots I$) T.V. to unhook and be made ready to travel after the last payload unit unloaded into the i th T.V. has been properly secured. [$0. < TTV_{10,i} \leq 9999$ (treated as a floating point number)].
- $TTV_{11,i}$ giving the time required for the i th ($i = 1, 2 \dots I$) T.V. to reach W.A.II from any of the ship unloading areas [$0. < TTV_{11,i} \leq 9999$ (treated as a floating point number)].
- $TTV_{13,i}$ giving the time required for the i th ($i = 1, 2 \dots I$) T.V. to reach any of the beach unloading areas from W.A.II and then beach and be made ready for the unloading operation. Note that the i th T.V. can leave W.A.II only when there is a beach unloading area free to receive it [$0. < TTV_{13,i} \leq 9999$ (treated as a floating point number)].
- $TTV_{15,i}$ giving the time required for the i th ($i = 1, 2 \dots I$) T.V. to be made ready to travel again after the last payload unit carried on any of its trips has been secured to the appropriate B.U.F. [$0. < TTV_{15,i} \leq 9999$ (treated as a floating point number)].
- $TTV_{16,i}$ giving the time required for the i th ($i = 1, 2 \dots I$) T.V. to reach W.A.I from any of the beach unloading areas after it has been made ready to travel [$0. < TTV_{16,i} \leq 9999$ (treated as a floating point number)].

- $TTV_{17,i}$ giving the time required for the i th ($i = 1, 2 \dots I$) T.V. to reach its base from any of the beach unloading areas after it has completed its mission [$0. < TTV_{17,i} \leq 9999$ (treated as a floating point number)].
- $IDTV_{j_7,i}^*$ indicating the nature of each of the j_7 ($1, 2 \dots 5, 9, 10 \dots 13, 15, 16, 17$) processes described above** for each of the i ($i = 1, 2 \dots I$) T.V.
- $INTV_{j_7,i}$ giving the seed of the $U(0,1)$ distribution which serves to predict the stochastic behavior of each of the j_7 ($j_7 = 1, 2 \dots 5, 9, 10 \dots 13, 15, 16, 17$) processes described above for each i ($i = 1, 2 \dots I$), if $IDTV_{j_7,i} = 2^{***}$ [$1 \leq INTV_{j_7,i} \leq 10^9 - 1$].
- $AMINTV_{j_7,i}$ giving the minimum value of the range of variation of $TTV_{j_7,i}$ ($j_7 = 1, 2 \dots 5, 9, 10 \dots 13, 15, 16, 17$; $i = 1, 2 \dots I$), if $IDTV_{j_7,i} = 2^{***}$ [$-999.99999 \leq AMINTV_{1,i} < 9999.99999$; $0. < AMINTV_{j_8,i} < 9999.99999$, $j_8 = 2, 3 \dots 5, 9, 10 \dots 13, 15, 16, 17$].
- $AMAXTV_{j_7,i}$ giving the maximum value of the range of variation of $TTV_{j_7,i}$ ($j_7 = 1, 2 \dots 5, 9, 10 \dots 13, 15, 16, 17$; $i = 1, 2 \dots I$), if $IDTV_{j_7,i} = 2^{***}$ [$-999.99999 < AMAXTV_{1,i} \leq 9999.99999$; $0. < AMAXTV_{j_8,i} \leq 9999.99999$, $j_8 = 2, 3 \dots 5, 9, 10 \dots 13, 15, 16, 17$].

* $IDTV_{j_7,i} = 1$ if the process is deterministic.
 $= 2$ if the process is stochastic, drawn from $U(0,1)$ distribution.
 $= 3, 4 \dots 9999$ if the process is stochastic, drawn from distributions to be developed by the user, if so desired.

**Processes 3 and 12 are associated with the waiting of a T.V. in W.A.I and W.A.II respectively.
6 and 7 are always deterministic.

***If $IDTV_{j_7,i} = 1$, then $INTV_{j_7,i}$, $AMINTV_{j_7,i}$ and $AMAXTV_{j_7,i}$ are not problem variables.

- WT1MAX* giving the maximum time that any of the *I* T.V. is expected to wait in W.A.I at any time during the mission [$0. < WT1MAX \leq 9999999.99$].
- WT2MAX* giving the maximum time that any of the *I* T.V. is expected to wait in W.A.II at any time during the mission [$0. < WT2MAX \leq 9999999.99$].
- IDBRTV*_{*j*₉,*i*}* indicating the presence or absence of breakdown considerations for each of the *j*₉ (*j*₉ = 1,2...8) processes (see Table 3-1) for the *i*th (*i* = 1,2...*I*) T.V. and, in the event that breakdown considerations are present, their nature.
- INBRTV*_{*j*₉,*i*} giving the seed of the $U(0,1)$ distribution which serves to predict the stochastic behavior of each of the *j*₉ (*j*₉ = 1,2...8) processes described above for each *i* (*i* = 1,2...*I*), if *IDBRTV*_{*j*₉,*i*}=2** [$1 \leq INBRTV_{j_9,i} \leq 10^9 - 1$].
- BRKTV*_{*j*₉,*i*} giving the probability that a breakdown will occur during the *j*₁₀th (*j*₁₀ = 1,3,4,6,7,8) process for each *i* (*i* = 1,2...*I*), and the probability that a breakdown will occur if the *i*th T.V. waited *WT1MAX* or more units of time in W.A.I during the 2nd process*** and the probability that a breakdown will occur if the *i*th T.V. waited *WT2MAX* or more units of time in W.A.II during the 5th process***, if *IDBRTV*_{*j*₉,*i*} = 2** [$0. < BRKTV_{j_9,i} < 1.0000$].

**IDBRTV*_{*j*₉,*i*} = 1 if there are no breakdown considerations.
 = 2 if there are breakdown considerations which are drawn from a $U(0,1)$ distribution.
 = 3,4...99 if there are breakdown considerations which are drawn from distributions to be developed by the user, if so desired.

** If *IDBRTV*_{*j*₉,*i*}=1, then *INBRTV*_{*j*₉,*i*} and *BRKTV*_{*j*₉,*i*} are not problem variables.

*** If the T.V. waited less the probability is scaled down linearly.

-
- i_9 = 1 Describes the breakdown considerations of each T.V. regarding its trip to W.A.I from its base. The breakdown considerations of this process are a function of the T.V. involved.
- = 2 Describes the breakdown considerations of each T.V. regarding its waiting in W.A.I. The breakdown considerations of this process are a function of the T.V. involved and the waiting time.
- = 3 Describes the breakdown considerations of each T.V. regarding its trip to any of the ship unloading areas from W.A.I. The breakdown considerations of this process are a function of the T.V. involved.
- = 4 Describes the breakdown considerations of each T.V. regarding its trip to W.A.II from any of the ship unloading areas. The breakdown considerations of this process are a function of the T.V. involved.
- = 5 Describes the breakdown considerations of each T.V. regarding its waiting in W.A.II. The breakdown considerations of this process are a function of the T.V. involved and the waiting time.
- = 6 Describes the breakdown considerations of each T.V. regarding its trip to any of the beach unloading areas from W.A.II. The breakdown considerations of this process are a function of the T.V. involved.
- = 7 Describes the breakdown considerations of each T.V. regarding its trip to W.A.I from any of the beach unloading areas. The breakdown considerations of this process are a function of the T.V. involved.
- = 8 Describes the breakdown considerations of each T.V. regarding its trip to its base from any of the beach unloading areas. The breakdown considerations of this process are a function of the T.V. involved.

Table 3-1

Processes Describing Breakdown Considerations

With the above, the list of the variables that are utilized to define the five subsystems involved in our study and at the same time appear as input in our computer program is complete. There exist two additional inputs to the computer program which serve to control the program's performance and which for the sake of completeness we include here. These are:

NCASES giving the number of cases to be processed in each program execution [$1 \leq \text{NCASES} \leq 99$], and
 NRUNS giving the number of runs to be processed for the j_1 th ($j_1 = 1, 2, \dots, \text{NCASES}$) case [$1 \leq \text{NRUN} \leq 500$].

We continue now by listing the remaining variables necessary to complete each subsystem's description.

MOTHER SHIP DESCRIPTION

The additional variables selected to complete the description of the Mother Ship's performance are:

TAMP, *T1P*, *T2P** giving the time fluctuation associated with *TAM*, *T1* and *T2* respectively.

TTM giving the total time taken by the Mother Ship to complete its operation. This includes the time taken to free the Mother Ship from its mooring and to make it ready for travel again after all S.U.F. are secured in position and all T.V. have cleared the Mother Ship.

* If *IDMA* and/or *ID1* and/or *ID2* equal 1, then *TAMP* and/or *T1P* and/or *T2P* equal zero respectively. If that is not the case, *TAMP*, *T1P* and *T2P* are determined by drawing from the appropriate distribution, as dictated by the magnitude of *IDMA*, *ID1* and *ID2* respectively.

PAYLOAD DESCRIPTION

The variables given above suffice to describe the payload characteristics to the degree of accuracy and extent desired, and so no additional variables are needed.

S.U.F. DESCRIPTION

The additional variables selected to complete the description of the S.U.F.'s performance are:

$TSC_{6,k}$ giving the time that the k th ($k = 1, 2 \dots K$) S.U.F. has to wait in the k th ship unloading area before it can unload the payload unit that it is transporting. The k th S.U.F. has to wait until the appropriate T.V. is properly secured in the k th ship unloading area or until the previously unloaded payload unit is properly secured in the T.V. in question. (This process is always deterministic.)

$TSCP_{j_2,k}^*$ giving the time fluctuation associated with $TSC_{j_2,k}$ ($j_2 = 1, 2 \dots 5, 7, 8, 9; k = 1, 2 \dots K$).

$AMAXSC_{6,k}$ giving the total time taken by the k th ($k = 1, 2 \dots K$) S.U.F. to complete its mission. This includes the time taken to secure the S.U.F. in its original position.

*If $IDSC_{j_2,k}$ equals 1, then $TSCP_{j_2,k}$ equals zero. If that is not the case, $TSCP_{j_2,k}$ is determined by drawing from the appropriate distribution, as dictated by the magnitude of $IDSC_{j_2,k}$.

B.U.F. DESCRIPTION

The additional variables selected to complete the description of the B.U.F.'s performance are:

$TBC_{5,\ell}$ giving the time that the ℓ th ($\ell = 1, 2, \dots, L$) B.U.F. has to wait in any of the beach unloading areas before it can release the appropriate payload unit. The ℓ th B.U.F. has to wait in a beach unloading area until the appropriate T.V. is properly beached and has been made ready for the unloading operation. (This process is always deterministic.)

$TBCP_{j_4,\ell}^*$ giving the time fluctuation associated with $TBC_{j_4,\ell}$ ($j_4 = 1, 2, 3, 4, 6, 7, \dots, 10$; $\ell = 1, 2, \dots, L$).

$AMAXBC_{5,\ell}$ giving the total time taken by the ℓ th ($\ell = 1, 2, \dots, L$) B.U.F. to complete its mission. This includes the time taken for the ℓ th B.U.F. to reach its base.

*If $IDBC_{j_4,\ell}$ equals 1, then $TBCP_{j_4,\ell}$ equals zero. If that is not the case, $TBCP_{j_4,\ell}$ is determined by drawing from the appropriate distribution, as dictated by the magnitude of $IDBC_{j_4,\ell}$.

T.V. DESCRIPTION

The additional variables selected to complete the description of the T.V.'s performance are:

$TTV_{3,i}$ giving the time that the i th ($i = 1, 2, \dots, I$) T.V. has to wait in W.A.I. The i th T.V. has to wait in W.A.I until the appropriate* ship unloading area becomes free to receive it. At the start of the mission, as soon as the Mother Ship is moored, all ship unloading areas become free. Subsequently, a ship unloading area becomes free as soon as the T.V. that is being served alongside the ship unloading area in question is unhooked and made ready to commence its journey to W.A.II.

$TTV_{8,i}$ giving the time that the i th ($i = 1, 2, \dots, I$) T.V. has to wait in any of the ship unloading areas awaiting the appropriate S.U.F.'s arrival.**

$TTV_{12,i}$ giving the time that the i th ($i = 1, 2, \dots, I$) T.V. has to wait in W.A.II. The i th T.V. has to wait in W.A.II until the appropriate***beach unloading area becomes free to receive it. At the start of the mission, as soon as the l th ($l = 1, 2, \dots, L$) B.U.F. arrives at point A, the l th beach unloading area becomes free. Subsequently a beach unloading area becomes free as soon as the T.V. that is being served at the beach unloading area in question is made ready to travel again for W.A.I.

* Note that during the sequential loading mode if one ship unloading area is not free, then all ship unloading areas are considered busy.

**This process is always deterministic.

***Note that during the sequential unloading mode if one beach unloading area is not free then all beach unloading areas are considered busy.

$TTV_{14,i}$ giving the time that the i th ($i = 1, 2 \dots I$) T.V. 42.
has to wait in any of the beach unloading areas
awaiting the appropriate B.U.F.'s arrival (this
process is always deterministic).

$TTVP_{j_7,i}^*$ giving the time fluctuation associated with
 $TTV_{j_7,i}$ ($j_7 = 1, 2 \dots 5, 9, 10 \dots 13, 15, 16, 17$; $i =$
 $1, 2 \dots I$).

$AMAXTV_{8,i}$ giving the total time taken by the i th ($i = 1, 2 \dots I$)
T.V. to complete its mission. This includes the
time taken for the i th T.V. to reach its base.

The above completes the list of variables that we
selected to describe our system for this study. We now pro-
ceed with the second topic of the Problem Definition, which
deals with the establishment of the relations among the
problem variables.

*If $IDTV_{j_7,i}$ equals 1, then $TTVP_{j_7,i}$ equals zero. If that is
not the case, $TTVP_{j_7,i}$ is determined by drawing from the
appropriate distribution, as dictated by the magnitude of
 $IDTV_{j_7,i}$.

ii) Establishment of the Relations Among the Problem Variables

Because in the fourth section we will undertake to construct the mathematical model of our system, we should, before we proceed, establish all the relationships that exist among the variables that we selected to describe our system. This is because the mathematical model is, by definition, the replica of our system in the form of mathematical equations, and therefore any such relations must be part of it in order to permit it to be a true replica of the original. So we proceed by establishing all such relationships.

(3.1)

$$TAMP = 0 \quad \text{if } IDMA = 1$$

$$= (AMAXM-AMINM)*R + AMINM - TAM \text{ if } IDMA = 2$$

where R is a random number generated from a $U(0,1)$ distribution utilizing $INMS$ as the first seed and then the updated $INMS$ in subsequent generations.

$$T1P = 0 \quad \text{if } ID1 = 1 \tag{3.2}$$

$$= (AMAX1-AMIN1)*R + AMIN1 - T1 \text{ if } ID1 = 2$$

where R is a random number generated from a $U(0,1)$ distribution utilizing $IN1$ as the first seed and then the updated $IN1$ in subsequent generations.

$$T2P = 0 \quad \text{if } ID2 = 1 \tag{3.3}$$

$$= (AMAX2-AMIN2)*R + AMIN2 - T2 \text{ if } ID2 = 2$$

where R is a random number generated from a $U(0,1)$ distribution utilizing $IN2$ as the first seed and then the updated $IN2$ in subsequent generations.

$$TTM = TAM + TAMP + T1 + T1P + T2 + T2P +$$

$$\max \left\{ \max_k \left(AMAXSC_{\theta,k} \right)^*, \max_k \left(TSCP_{\theta,k} \right)^{**} \right\} \quad (3.4)$$

where $TSCP_{\theta,k}$ records the last time that the k th ($k = 1, 2, \dots, K$) ship unloading area became free.

$$TSCP_{j_2,k} = 0 \quad \text{if } IDSC_{j_2,k} = 1 \quad (3.5)$$

$$= \left(AMAXSC_{j_2,k} - AMINSC_{j_2,k} \right) * R + AMINSC_{j_2,k}^{-TSC_{j_2,k}}$$

$$\text{if } IDSC_{j_2,k} = 2$$

where R is a random number generated from a $U(0,1)$ distribution utilizing $INSC_{j_2,k}$ ($j_2 = 1, 2, \dots, 5, 7, 8, 9$; $k = 1, 2, \dots, K$) as the first seed and then the updated $INSC_{j_2,k}$ in subsequent generations.

$TSC_{\theta,k}$, $AMAXSC_{\theta,k}$ The relationships of $TSC_{\theta,k}$, $AMAXSC_{\theta,k}$ (3.6, 3.7) with the other problem variables are too cumbersome to be written in the form of mathematical equations, and so the reader is referred to the listing of the computer program, where the relationships in question are given in the form of computer coding. The mathematical form of these relationships can be obtained from the computer coding, if so desired, and it is similar to the form of equation (3.4).

*The magnitude of $AMAXSC_{\theta,k}$ at the conclusion of the mission of the k th S.U.F.

**The magnitude of $TSCP_{\theta,k}$ immediately after the last of the N_k payload units has been unloaded and secured in the appropriate T.V., and after the T.V. in question has been unhooked and made ready to depart for W.A.II.

$$TBCP_{j_4, \ell} = 0 \quad \text{if } IDBC_{j_4, \ell} = 1 \quad (3.8)$$

$$= \left(AMAXBC_{j_4, \ell} - AMINBC_{j_4, \ell} \right) * R + AMINBC_{j_4, \ell}^{-TBC_{j_4, \ell}}$$

if $IDBC_{j_4, \ell} = 2$

where R is a random number generated from a $U(0,1)$ distribution utilizing $INBC_{j_4, \ell}$ ($j_4 = 1, 2, 3, 4, 6, 7 \dots 10$; $\ell = 1, 2 \dots L$) as the first seed and then the updated $INBC_{j_4, \ell}$ in subsequent generations.

$$TBC_{5, \ell}, AMAXBC_{5, \ell} \quad (3.9, 10)$$

The comments given for equations (3.6) and (3.7) apply also for equations (3.9) and (3.10).

$$TTVP_{j_7, i} = 0 \quad \text{if } IDTV_{j_7, i} = 1 \quad (3.11)$$

$$= \left(AMAXTV_{j_7, i} - AMINTV_{j_7, i} \right) * R + AMINTV_{j_7, i}^{-TTV_{j_7, i}}$$

if $IDTV_{j_7, i} = 2$

where R is a random number generated from a $U(0,1)$ distribution utilizing $INTV_{j_7, i}$ ($j_7 = 1, 2 \dots 5, 9, 10 \dots 13, 15, 16, 17$; $i = 1, 2 \dots I$) as the first seed and then the updated $INTV_{j_7, i}$ in subsequent generations.

$$TTV_{j_{11}, i}, AMAXTV_{8, i} \quad (3.12-16)$$

$$j_{11} = 3, 8, 12, 14$$

The comments given for equations (3.6) and (3.7) apply also for equations (3.12)-(3.16)

The above equations establish all the relationships that exist among the problem variables. Now we proceed with the discussion of the third topic in the Problem Definition, namely, the identification of the dependent and independent variables.

iii) Identification of the Dependent and Independent Variables

For reasons given in the previous section it is necessary, before we proceed any further, to classify the problem variables into dependent and independent ones. As a reminder, the independent variables are those variables which must be prescribed to completely describe our system as desired. The dependent variables are the ones remaining in our original list of variables after the independent ones have been removed. The value of the dependent variables can be obtained from the variable interrelationships.

The variable classification of dependent and independent variables can be accomplished in the following manner:

For each interrelation, one of the variables involved is classed as a dependent variable and all the others are classed as independent variables. With this method, if the same variable is involved in more than one interrelation, it cannot be selected to serve as a dependent variable more than once.

In theory, any of the variables involved in an interrelation can be classed as a dependent variable. However, in practice, whenever it is possible we usually attempt to class as dependent variables the ones that allow us to simplify our methodology as much as possible, and we attempt to class as

independent variables the ones which are the most meaningful to the user so he can assign their values with confidence. Whenever, as in our case, that is impossible because of the nature of the interrelations, we usually must compromise. The nature of the equations (3.1)-(3.16) forces us to class the variables appearing on the left-hand side of these equations as the dependent variations. However, although we have no choice in our selection, there was no compromise at all, as the resulting independent variables of our problem are both the most meaningful of the variables to the user, and at the same time they allow us to simplify our methodology the most.

So our dependent variables are:

$TAMP, T1P, T2P, TTM,$

$TSCP_{j_2, k}, TSC_{6, k}, AMAXSC_{6, k} \quad (j_2=1, 2, \dots, 5, 7, 8, 9; k=1, 2, \dots, K)$

$TBCP_{j_4, \ell}, TBC_{5, \ell}, AMAXBC_{5, \ell} \quad (j_4=1, 2, 3, 4, 6, 7, \dots, 10; \ell=1, 2, \dots, L)$

$TTVP_{j_7, i}, TTV_{j_{11}, i}, AMAXTV_{8, i} \quad (j_7=1, 2, \dots, 5, 9, 10, \dots, 13, 15, 16, 17;$
 $j_{11}=3, 8, 12, 14; i=1, 2, \dots, I)$

and our independent variables are:

$TAM, T1, T2, IDMA, ID1, ID2, INMS, AMINM, AMAXM, IN1, AMIN1,$
 $AMAX1, IN2, AMIN2, AMAX2,$

$N_k, WC_n, VC_n \quad (k=1, 2, \dots, K; n=1, 2, \dots, \sum_{k=1}^K N_k)$

$K, ISUD, ISCSL, TSC_{j_2, k}, IDSC_{j_2, k}, INSC_{j_2, k}, AMINSC_{j_2, k},$
 $AMAXSC_{j_2, k} \quad (j_2=1, 2, \dots, 5, 7, 8, 9; k=1, 2, \dots, K)$

$L, IBUD, IBCSL, TBC_{j_4, \ell}, IDBC_{j_4, \ell}, INBC_{j_4, \ell}, AMINBC_{j_4, \ell},$
 $AMAXBC_{j_4, \ell} \quad (j_4 = 1, 2, 3, 4, 6, 7, \dots, 10; \ell=1, 2, \dots, L)$

$I, IWA1SL, IWA2SL, ICHANG, AMAXTV_{6,i}, AMAXTV_{7,i}, TTV_{j_6,i},$
 $IDTV_{j_7,i}, INTV_{j_7,i}, AMINTV_{j_7,i}, AMAXTV_{j_7,i}, WT1MAX,$
 $WT2MAX, IDBRTV_{j_9,i}, INBRTV_{j_9,i}, BRKTV_{j_9,i}$
 $(j_6=1,2,4,5,6,7,9,10,11,13,15,16,17; j_7=1,2\dots5,9,10\dots13,$
 $15,16,17; j_9=1,2\dots8; i=1,2\dots I)$

TIME, WGHT and VOL.

The above completes our discussion about the identification of the dependent and independent variables of our problem, and now we may proceed with the discussion of the establishment of the range of variation of our problem's parameters.

iv) Establishment of the Range of Variation of the Problem Parameters

For the reasons given in the previous section, it was found necessary to introduce limitations on the range of variation of our problem's parameters. The limitations introduced in our study are enumerated and explained below. Methods for alleviating each limitation when it is found unacceptable are also given below, whenever it is deemed necessary. For clearer understanding of certain of the limitations listed below, the user is advised to refer to Fig. 3-1, where the subsystems involved in our study are shown diagrammatically.

1. The entire operation is assumed to have started* either when the mother ship arrives at the theater of operations or when one or more T.V. or B.U.F. start from their bases. This limitation can be alleviated easily by assuming that the entire operation commences at any prespecified time, as desired.
2. The entire operation finishes when the mother ship is freed from its moorings and is ready to depart, and all the T.V. and B.U.F. reach their appropriate bases. This limitation

*At the start of the operation the time counter in our program is initialized to zero.

can be alleviated easily by assuming that the entire operation terminates at any prespecified time, as desired.

3. As was already noted in the discussion of the first topic of this section, limitations of the form $y_{min} \leq y \leq y_{max}$ (where y is any of our independent variables or NCASES and NRUNS) were introduced controlling the magnitude variation of the different problem parameters. These limitations can be alleviated by changing the format and/or the dimension statements in the computer program.
4. The mission of each S.U.F. is such that it does not interfere with that of any other S.U.F.
5. Each of the K S.U.F. is assumed to complete its mission without any technical difficulties. This limitation can be alleviated by introducing breakdown considerations similar to those introduced for the T.V.
6. Each of the K S.U.F. requires no refuelling during its entire operation.
7. The unloading at the ship may be sequential or in parallel, but not both. In addition, the unloading mode at the ship is independent of that at the beach. Moreover, in the parallel unloading mode, the S.U.F. performance is not influenced by the number of S.U.F. that happen to be unloading at any instant of time.

8. The times $TSC_{2,3,4,5;k}$ depend on the S.U.F. characteristics only, and are independent of the payload unit they are to service.
9. The time $TSC_{7,k}$ depends on the S.U.F. characteristics only, and is independent of the payload unit that is being unloaded and the T.V. into which the payload unit in question is being loaded.
10. The payload units capable of self-induced rolling motion may be loaded into the T.V. by ramps. When this is done, the ramps are treated as regular S.U.F. and the times $TSC_{j_2,k'}$ ($j_2 = 1, 2, \dots, 5, 7, 8, 9$; $k' = I.D. \text{ of ramps}$) of each ramp are determined by averaging the unloading characteristics of the payload units that are to be unloaded by the ramp in question.
11. Each payload unit loaded at the area associated with the k th ($k = 1, 2, \dots, K$) S.U.F. can be unloaded only by the k th S.U.F.
12. The k th ($k = 1, 2, \dots, K$) S.U.F. is assumed to be able to handle the heaviest and bulkiest payload unit that is loaded in the area that is associated with the S.U.F. in question.
13. Only one payload unit may be handled by a S.U.F. at any one time.

14. Once a T.V. hooks up at the k th ($k = 1, 2, \dots, K$) ship unloading area, only the k th S.U.F. may load it.
15. Each of the I T.V. may hook up at one ship unloading area only during the execution of any one of its trips.
16. Each of the K S.U.F. continues to load in any of the I T.V. during the execution of any one of its trips until
 - i) no more payload units can be loaded into the T.V. in question, because the weight capacity of the T.V. will be exceeded, or
 - ii) no more payload units can be loaded into the T.V. in question because the volume capacity of the T.V. will be exceeded, or
 - iii) there are no more payload units to be unloaded by the S.U.F. in question, or
 - iv) any combination of the above statements becomes true.
17. The mission of each B.U.F. is such that it does not interfere with that of any other B.U.F.
18. Each of the L B.U.F. is assumed to complete its mission without any technical difficulties. This limitation can be alleviated by introducing breakdown considerations similar to those introduced for the T.V.
19. Each of the L B.U.F. requires no refuelling during the entire operation.

20. The unloading at the beach may be sequential or in parallel, but not both. In addition, the unloading mode at the beach is independent of that at the ship. Moreover, in the parallel unloading mode the B.U.F. performance is not influenced by the number of B.U.F. that happens to be unloading at any instant of time.
21. Times $TBC_{\delta, \gamma; \ell}$ depend on the B.U.F. characteristics only, and are independent of the payload unit that is being serviced and the T.V. from which the payload unit in question is being unloaded.
22. Time $TBC_{\delta, \ell}$ depends on the B.U.F. characteristics only, and is independent of the payload unit that is being serviced.
23. The payload units capable of self-induced rolling motion are unloaded from the T.V. by regular B.U.F. No special provisions have been made in this program to include any other type of beach unloading facilities.
24. Each of the L B.U.F. is assumed to be able to handle the heaviest and bulkiest payload unit.
25. Only one payload unit may be handled by B.U.F. at any one time.
26. Once a T.V. beaches at the ℓ th ($\ell = 1, 2, \dots, L$) beach unloading area, only the ℓ th B.U.F. may unload it.

27. Each of the I T.V. may beach at one beach unloading area only during the execution of any one of its trips.
28. Each of the L B.U.F. continues to unload from any of the I T.V. during the execution of any one of its trips until all the payload units carried by the T.V. in question in that particular trip have been unloaded.
29. When the i th ($i = 1, 2, \dots, I$) T.V. starts from its base it is assumed to have its normal fuel tanks fully loaded with fuel. In additional tanks that are so constructed as to not affect the volume of payload, sufficient fuel is carried to permit the i th T.V. to reach the W.A.I and then the appropriate ship unloading area where it hooks up and is made ready for the unloading operation, without using any of the fuel in the normal fuel tanks. Furthermore, it is assumed that the weight of this additional fuel is smaller than or equal to the weight of the payload.
30. The fuel stored in the regular fuel tanks must be sufficient to permit any T.V. to complete at least one round trip.
31. The fuel required for the T.V. to return to its base after execution of Step 11, as described in the mission of the i th ($i = 1, 2, \dots, I$) T.V. (see Section 4) is less than or equal to the fuel required for it to complete its round trip.

32. When a T.V. is to be refuelled, it is always refuelled completely.
33. The refuelling of the i th ($i = 1, 2 \dots I$) T.V. is to be effected only when it is alongside the mother ship, and at whatever ship unloading area it is hooked up.
34. The fuel requirements of the T.V. while waiting in queues I and II, while hooked up alongside the mother ship, and while beached at the shore, are negligible.
35. The time $TTV_{5,i}$ depends on the T.V. characteristics only, and is independent of the ship unloading area that is being serviced.
36. Each of the I T.V. must be able to transport the heaviest and bulkiest payload unit in any of its trips.
37. The T.V. are to carry payload only when they are traveling between the mother ship and the beach. At all other times, they do not carry any payload.
38. The mission of each T.V. is such that it does not interfere with that of any other T.V.
39. None of the I T.V. requires the assistance of any of the S.U.F. to perform Steps 3 and 6 as described in the mission of the i th ($i = 1, 2 \dots I$) T.V. (see Section 4).

40. None of the I T.V. requires the assistance of any of the B.U.F. to perform Steps 9 and 11 as described in the mission of the i th ($i = 1, 2, \dots, I$) T.V. (see Section 4).
41. The times $TTV_{4,10,11;i}$ depend on the T.V. characteristics only, and are independent of the S.U.F. that is being serviced.
42. The time $TTV_{9,i}$ depends on the T.V. characteristics only, and is independent of the S.U.F. and the payload units that are being serviced.
43. The times $TTV_{13,16,17;i}$ depend on the T.V. characteristics only, and are independent of the B.U.F. that is being serviced.
44. Each T.V. must wait (even if it is for zero time) in queues I and II respectively until the appropriate unloading areas are free to receive them.
45. The breakdown considerations for processes 1, 3, 4, 6, 7 and 8 (see Table 3-1) are functions of i only and are time invariant.
46. The breakdown considerations of processes 2 and 5 (see Table 3-1) are functions of i and waiting time only and are again time invariant.

47. All steps (as described in the mission of the i th ($i = 1, 2 \dots I$) T.V.) that can be performed before the breakdown considerations forcibly remove a T.V. from our system, are executed. (It is important to be aware of this limitation so that the concept of antithetic variance be introduced correctly into our methodology. It can be relaxed at will by changing the computer program accordingly.)
48. When the i th ($i = 1, 2 \dots I$) T.V. is executing any other segment of its trip not covered by processes 1-8 of Table 3-1, it is assumed that it cannot malfunction.

The above completes our discussion of the fourth topic of the Problem Definition. We now proceed with the discussion of the final topic in the Problem Definition, namely, the Selection of the Figure of Merit.

v) Selection of the Figure of Merit

Finally, as was already stated in the two previous sections, the figure of merit (the measure of success) is taken to be the weighted combination of mean time to closure and the mean number of transfer vehicles malfunctioning.

The above may be expressed mathematically as follows:

$$c = \text{Minimize } (W_1 T + W_2 B) \quad (3.17)$$

where

c is the figure of merit,

W_1 & W_2 are weighting factors denoting the relative weight that T and B will have on our decision

T is the time component of the figure of merit involving the calculation of the maximum mean time elapsed since the start of the mission to

1. prepare the Mother Ship for departure after all the payload has been transferred to the T.V. and all T.V. have cleared the Mother Ship,
2. complete the payload transfer from the Mother Ship to point A on the beach,
3. return all T.V. to their bases,
4. return all B.U.F. to their bases,

$$\text{i.e., } T = \text{Maximum}_{\substack{\ell=1, 2 \dots L \\ i=1, 2 \dots I}} \left\{ TTM, AMAXBC_{5, \ell}, AMAXTV_{8, i} \right\}^* \quad (3.18)$$

and B is the component of the figure of merit involving the calculation of the mean number of T.V. that did not complete their mission (see Section 4) because of breakdown.**

*Note that as each term involved in the right-hand side of equ. 3.18 is a random variable T is also a random variable.

**Note that as breakdown considerations are random in nature B is a random variable.

It is of interest to note, although it is not necessary for the development of this study, that if the user is an expected value decision maker equation (3.17), if properly used, should lead to the desired solution. However, as decision makers are not always expected value decision makers it is likely that equation (3.17) will not satisfy all the needs encountered in practice. For example, it might be desired that the decision should be based on a figure of merit defined as the weighted combination of the expected value and variance of the decision variables, or some other such scheme.* Bearing in mind this fact, although c as defined by equation (3.17) is used here, the output of this study is such as to allow the user to define c in such a manner as to reflect his thoughts on the matter.

The above completes the discussion on the Problem Definition, and now we may proceed with the discussion on the formulation of the Mathematical Model for our system.

*For a detailed analysis on the matter the reader is referred to any book dealing with the subject of Statistical Decision Theory, e.g., Raiffa, Howard and Schlaifer, Robert: Applied Statistical Decision Theory. Boston: Harvard University, 1961.

4. Formulation of the Mathematical Model

Instead of presenting the mathematical equations that make up the mathematical model for our study, the mission of each subsystem involved, the breakdown considerations, and the description of the use strategies are given. The reason for choosing this approach in describing the formulation of our mathematical model is because we achieve our goal more easily, as the nature of the underlying mathematical equations makes them very cumbersome to write.

As was stated in the second section of this report, the mathematical model of our study is so formulated as to be a replica of the system under consideration to the degree of accuracy and extent desired. Also, because of the type of problem we are dealing with, the nature of the model is stochastic. In setting up the mathematical model, care was taken to keep it as simple as possible to permit easy analysis and yet to construct it so that it exhibits all the phenomena under consideration, as required.

The description of the formulation of our mathematical model is presented in the following manner:

- i) Description of the mission of the Mother Ship. 62.
- ii) Description of the unloading procedure of the n th
($n = 1, 2, \dots, \sum_{k=1}^K N_k$) payload unit.
- iii) Description of the mission of the k th ($k=1, 2, \dots, K$) S.U.F.
- iv) Description of the mission of the ℓ th ($\ell=1, 2, \dots, L$) B.U.F.
- v) Description of the mission of the i th ($i=1, 2, \dots, I$) T.V.
- vi) Description of the breakdown considerations.
- vii) Description of the payload unloading strategy.
- viii) Description of the T.V. use strategy A for W.A.I.
- ix) Description of the T.V. use strategy B for W.A.I.
- x) Description of the T.V. use strategy C for W.A.I.
- xi) Description of the T.V. use strategy D for W.A.I.
- xii) Description of the T.V. use strategy E for W.A.I.
- xiii) Description of the T.V. use strategy A for W.A.II.
- xiv) Description of the T.V. use strategy B for W.A.II.
- xv) Description of the T.V. use strategy C for W.A.II.
- xvi) Description of the T.V. use strategy D for W.A.II.
- xvii) Description of the S.U.F. use strategy A .
- xviii) Description of the S.U.F. use strategy B .
- xix) Description of the S.U.F. use strategy C .
- xx) Description of the B.U.F. use strategy A .
- xxi) Description of the B.U.F. use strategy B .

i) Mission of the Mother Ship.

Step 1. The Mother Ship arrives at the theater of operations.

Step 2. The Mother Ship is properly moored in position after it arrives at the theater of operations. Upon completion of this step, all ship unloading areas become free for the first time.

Step 3. The Mother Ship is freed from its moorings and is made ready to travel after all S.U.F. are secured in position and all T.V. have cleared the Mother Ship.

Upon completion of Step 3 given above, the Mother Ship's mission is completed.

ii) Unloading Procedure of the n th ($n = 1, 2, \dots, \sum_{k=1}^K N_k$) Payload Unit.

Step 1 The n th payload unit is released after the appropriate S.U.F. has reached the payload unit in question.

Step 2 The n th payload unit is secured on the appropriate S.U.F. after the payload unit in question has been released.

Step 3 The n th payload unit is transported to the appropriate ship unloading area after it has been secured on the S.U.F. in question.

Step 4 The n th payload unit is unloaded into the appropriate T.V. and then freed from the S.U.F. in question. This operation is performed only if

- a) the appropriate T.V. has been properly secured in the ship unloading area and has been made ready for the loading operation and has completed its refueling (if refueling was necessary),
- b) the previous payload unit unloaded by the S.U.F. in question is fully secured in the T.V. in question (this requirement is void if the n th payload unit is the first payload unit to be unloaded in any of the T.V.'s trips), and
- c) the T.V.'s remaining capacity can accept the n th payload unit.

If that is not the case the n th payload unit 65.
will have to wait in the appropriate ship unloading
area until the above requirements are satisfied.

Step 5 The n th payload unit is secured in position on the
T.V. in question after it has been freed from the ap-
propriate S.U.F. and after the S.U.F. in question has
been made ready to travel again.

Step 6* The n th payload unit is transported to W.A.II from the
appropriate ship's unloading area. This operation is
performed only if

- a) the capacity of the T.V. in question is such that
it cannot accept the next payload unit or
- b) the n th payload unit was the last payload unit as-
sociated with the S.U.F. in question. If that is
not the case, the n th payload unit will wait along-
side the ship unloading area in question until one
or both of the above requirements are satisfied.

In addition, please note that the operation in-
volved in Step 6 is performed after

- a) the last payload unit unloaded into the T.V. in
question in any of its trips has been properly
secured, and
- b) after the T.V. in question has been unhooked
from the appropriate ship unloading area and has
been made ready for travel.

*Steps 6-11 will not be executed if the T.V. in question breaks
down while on route to W.A.II from the Mother Ship. The n th
payload unit together with the T.V. in question is then assumed
lost from our system.

Step 7* The n th payload unit waits in W.A.II after it has 66. arrived there until the appropriate B.U.F. is ready to receive the T.V. that carries the payload unit in question.

Step 8** The n th payload unit is transported to the appropriate beach unloading area from W.A.II after it has waited there appropriately until the beach unloading area in question is freed.

Step 9 The n th payload unit is released, utilizing the appropriate B.U.F. The operation is performed only if the T.V. in question is beached and ready to commence the unloading operation, if the appropriate B.U.F. has reached the appropriate beach unloading area, and if all the payload units loaded after the n th payload unit into the T.V. in question in this trip have been unloaded. If that is not the case, the releasing of the n th payload unit has to wait until the above requirements are satisfied.

Step 10 The n th payload unit is secured on the appropriate B.U.F. after it has been released.

*Steps 7-11 will not be executed if the T.V. in question breaks down while waiting in W.A.II. The n th payload unit together with the T.V. in question is then assumed lost from our system.

**Steps 8-11 will not be executed if the T.V. in question breaks down while on route to the beach from W.A.II. The n th payload unit together with the T.V. in question is then assumed lost from our system.

Step 11 After the n th payload unit is secured on the appropriate B.U.F. it is

- a) transported from the appropriate beach unloading area to point A on the beach by utilizing the appropriate B.U.F.,
- b) unloaded at point A , and then
- c) freed from the B.U.F. in question.

Upon completion of Step 11 given above, the n th payload unit is considered to have reached its destination.

iii) Mission of the k th ($k = 1, 2, \dots, K$) S.U.F.

Step 1 The k th S.U.F. is made ready to start the unloading operation and is allowed to reach the k th ship unloading area after the Mother Ship is properly moored.

Step 2 The k th S.U.F. travels to the appropriate payload unit from the k th ship unloading area after it has been made ready to travel, or after the above step is completed.

Step 3 The k th S.U.F. releases the appropriate payload unit after the k th S.U.F. has reached the payload unit in question.

Step 4 The k th S.U.F. has the payload unit in question secured onto it after the payload unit in question has been released.

Step 5 The k th S.U.F. transports the payload unit in question to the k th ship unloading area after the above mentioned payload unit has been secured on the k th S.U.F.

Step 6 The k th S.U.F. unloads the payload unit in question into the appropriate T.V. and releases it, and then the k th S.U.F. is made ready to travel again. This operation is performed only if

- a) the appropriate T.V. is properly secured in the k th ship unloading area and has been made ready for the loading operation and has completed its refueling (if refueling was necessary),
- b) the previous payload unit unloaded by the k th S.U.F. is fully secured in the T.V. in question (this requirement is void if the payload unit in question is the first payload unit to be unloaded in any of the T.V.'s trips), and
- c) the T.V.'s remaining capacity can accept the payload unit in question.

If any of the above is not satisfied, the k th S.U.F. must wait until all three requirements given above are satisfied.

Step 7 The k th S.U.F. is allowed to travel back to its original position from the k th ship unloading area and then be secured to its original position after all the N_k payload units have been unloaded into the T.V.

Upon completion of Step 7 given above, the mission of the k th S.U.F. is completed. Please note that when Steps 2-6 given above are executed, the k th S.U.F. is then said to have executed one unloading cycle. It then follows that during its mission, the k th S.U.F. will execute N_k unloading cycles. The completion of an unloading cycle automatically starts the next one until all N_k unloading cycles have been executed.

iv) Mission of the ℓ th ($\ell = 1, 2, \dots, L$) B.U.F.

70.

Step 1 The ℓ th B.U.F. starts from its base having as its final destination point A on the beach. Upon arrival, the ℓ th beach unloading area becomes free for the first time.

Step 2 The ℓ th B.U.F. is made ready to start the unloading operation after the ℓ th B.U.F. has reached point A on the beach.

Step 3 The ℓ th B.U.F. travels to the ℓ th beach unloading area after it has been made ready to travel.

Step 4 The ℓ th B.U.F. releases the appropriate payload unit after it has reached the ℓ th beach unloading area. This operation, of course, is performed only if the appropriate T.V. is beached and is ready to commence the unloading operation. If that is not the case, the ℓ th B.U.F. must wait for the T.V. in question to arrive, to be beached and to be made ready for the unloading operation.

Step 5 The ℓ th B.U.F. has the payload unit in question secured onto it after the payload unit has been released.

Step 6 The ℓ th B.U.F. (after the payload unit in question has been secured onto it) transports the payload unit in question from the ℓ th beach unloading area to point A on the beach. After that, it releases the unit and the

B.U.F. in question is made ready to travel again.

Step 7 The ℓ th B.U.F. is secured in its original position and is prepared for departure after its unloading mission* has been completed.

Step 8 The ℓ th B.U.F. is allowed to return to its base after it has been prepared for departure.

Upon completion of Step 8 given above, the mission of the ℓ th B.U.F. is completed. Please note that when Steps 3-6 given above are executed, the ℓ th B.U.F. is said to have executed one unloading cycle. The completion of an unloading cycle automatically starts the next unloading cycle until the unloading mission of the B.U.F. in question has been completed.

*The unloading mission of the ℓ th B.U.F. is assumed to be completed when the ℓ th B.U.F. is not needed to unload any more payload units.

v) Mission of the i th ($i = 1, 2, \dots, I$) T.V.

- Step 1* The i th T.V. starts from its base having as its final destination W.A.I, where it joins queue I.
- Step 2** The i th T.V. waits in queue I after it arrives in W.A.I until the appropriate ship unloading area is freed.*** (As mentioned earlier at the start of the mission, as soon as the Mother Ship is moored, all ship unloading areas become free. Subsequently, a ship unloading area becomes free as soon as the T.V. that is being served alongside the ship unloading area in question is unhooked and made ready to commence its journey to W.A.II.)
- Step 3**** The i th T.V. departs from W.A.I for the Mother Ship where it hooks up to the appropriate ship unloading area as soon as it is reached, and then the i th T.V. is made ready for the loading operation. The T.V. in question departs from W.A.I only after the appropriate ship unloading area is free to receive it.

*Steps 1-13 will not be executed if the T.V. in question breaks down while on route to W.A.I from its base. The i th T.V. is then assumed lost from our system.

**Steps 2-13 will not be executed if the T.V. in question breaks down while waiting in W.A.I. The i th T.V. is then assumed lost from our system.

***In the sequential loading mode when one ship unloading area is not free, then all ship unloading areas are considered busy.

****Steps 3-13 will not be executed if the T.V. in question breaks down while on route from W.A.I to the appropriate ship unloading area. The i th T.V. is then assumed lost from our system.

Step 4 The i th T.V. is refuelled (if refueling is necessary).

Step 5 The appropriate payload unit is secured onto the i th T.V. after the payload unit in question has been unloaded into the i th T.V. and freed from the appropriate S.U.F., and after the S.U.F. in question has been made ready to travel. If the time taken in this trip for the i th T.V. to secure the payload unit previously unloaded (if there was one) onto the i th T.V. is less than the time taken to execute Steps 2-5 given in the mission of the k th ($1, 2 \dots K$) S.U.F., then the i th T.V. waits until the above mentioned Steps 2-5 are completed.

Step 6 The i th T.V. is unhooked from the ship unloading area in question and is made ready to travel after the last payload unit to be unloaded into the i th T.V. in this trip of the T.V. in question has been properly secured. (As mentioned earlier, upon completion of this step, the ship unloading area in question becomes free.)

Step 7* The i th T.V. starts from the ship unloading area in question having as its final destination W.A.II, where it joins queue II after it has been made ready to travel.

*Steps 7-13 will not be executed if the i th T.V. breaks down while on route from the ship unloading area in question to W.A. II. The payload that was being transported on this trip of the i th T.V. and the T.V. itself are then assumed lost from our system.

Step 8* The i th T.V. waits in queue II after it arrives at W.A.II, until the appropriate beach unloading area is freed**. (As mentioned earlier at the start of the mission, as soon as the l th ($l = 1, 2, \dots, L$) B.U.F. arrives at point A , the l th beach unloading area becomes free. Subsequently, a beach unloading area becomes free as soon as the T.V. that is being served at the beach unloading area in question is made ready to travel again for W.A.I.)

Step 9*** The i th T.V. departs from W.A.II for the shore, where it beaches at the appropriate beach unloading area as soon as it is reached and then the i th T.V. is made ready for the unloading operation. The T.V. in question departs from W.A.II only after the appropriate beach unloading area is free to receive it.

*Steps 8-13 will not be executed if the T.V. in question breaks down while waiting in W.A.II. The payload that was being transported on this trip of the i th T.V. and the T.V. itself are then assumed lost from our system.

**In the sequential unloading mode, when one beach unloading area is not free, then all beach unloading areas are considered busy.

***Steps 9-13 will not be executed if the T.V. in question breaks down while on route from W.A.II to the appropriate beach unloading area. The payload that was being transported on this trip of the i th T.V. and the T.V. itself are then assumed lost from our system.

Step 10 The appropriate payload unit is released from the i th T.V. by the appropriate B.U.F. after the B.U.F. in question has reached the i th T.V. Next, the appropriate payload unit is secured onto the B.U.F. in question. While the above mentioned B.U.F. is executing first the sixth and then the third step described in the mission of the l th ($l = 1, 2, \dots, L$) B.U.F., the i th T.V. waits in the beach unloading area in question until the above mentioned two steps are completed.

Step 11 The i th T.V. is made ready to travel after the last payload unit carried by the i th T.V. in this trip of the T.V. in question has been secured onto the appropriate B.U.F. (As mentioned earlier upon completion of this step the beach unloading area in question becomes free.)

Step 12* The i th T.V. starts from the beach unloading area in question having as its final destination W.A.I, where it joins queue I after it has been made ready to travel. This operation is performed only if the transporting mission** of the i th T.V. has not been completed.***

Step 13****The i th T.V. starts from the beach unloading area in question after it has been made ready to travel, having as its final destination the T.V.'s base.

Upon completion of Step 13 given above, the mission of the i th T.V. is completed. Please note that when Steps 2-12 given above are executed, the i th T.V. is said to have executed one complete trip. The completion of a trip automatically starts the next trip until the transporting mission of the T.V. in question is completed.

*Steps 12 and 13 will not be executed if the i th T.V. breaks down while on route from the beach unloading area in question to W.A.I. The i th T.V. is then assumed lost from our system.

**The transporting mission of the i th T.V. is assumed to be completed when the i th T.V. is not needed to transport any more payload units.

***In our mathematical model Step 12 is always executed as long as there is even one payload unit on board the Mother Ship. However, this action is forfeited for all the T.V. that happen to be in W.A.I immediately after the appropriate T.V. departed W.A.I to load the last payload unit(s) from the Mother Ship.

****Step 13 will not be executed if the T.V. breaks down while on route from the beach unloading area in question to the T.V.'s base. The i th T.V. is then assumed lost from our system.

vi) Breakdown Considerations

If $IDBRTV_{j_g, i} = 1$ ($j_g = 1, 2, \dots, 8$; $i = 1, 2, \dots, I$) there are no breakdown considerations involved in our analysis for the part of the journey of the i th T.V. described by the j_g th process, and so the discussion given here does not apply for that T.V. and that part of its journey.

Before the i th T.V. is allowed to complete its journey to W.A.I from its base, a random number, R , is generated from the appropriate distribution, as dictated by $IDBRTV_{1, i}$, utilizing $INBRTV_{1, i}$ as the first seed*. If

$$R < BRKTV_{1, i} \quad (4.1)$$

then the i th T.V. is assumed lost from our system. If equation (4.1) is not satisfied, then the i th T.V. is allowed to enter W.A.I and it is assumed that no breakdown has occurred in the part of the journey of the i th T.V. described above.

In the mathematical model of our system, a record of the T.V. lost at this stage is kept. If, at the end of the Mother Ship's mission, any of these T.V. has not been selected at all by the appropriate T.V. use strategy for W.A.I, a note to the user is given stating that fact.

Before the i th T.V. is allowed to depart from W.A.I, a random number, R , is generated from the appropriate

*The updated $INBRTV_{1, i}$ are used as the seeds of subsequent generations.

distribution, as dictated by $IDBRTV_{2,i}$, utilizing $INBRTV_{2,i}$ as the first seed*.

If

$$R < \frac{TTVP_{6,i}}{WT1MAX} * BRKTV_{2,i} \quad (4.2)$$

where $TTVP_{6,i}$ = total waiting time of the i th T.V. in W.A.I in this trip of the T.V. in question.

$$\text{if} \quad TTVP_{6,i} < WT1MAX \quad (4.3)$$

$$\text{or if} \quad R < BRKTV_{2,i} \quad (4.2)$$

$$\text{if} \quad TTVP_{6,i} \geq WT1MAX \quad (4.3)$$

then the i th T.V. is assumed lost from our system. If equation (4.2) is not satisfied, then the i th T.V. is allowed to depart from W.A.I for the appropriate ship unloading area and it is assumed that no breakdown has occurred while the T.V. in question was waiting in W.A.I.

Before the i th T.V. is allowed to reach the appropriate ship unloading area from W.A.I, a random number, R , is generated from the appropriate distribution, as dictated by $IDBRTV_{3,i}$, utilizing $INBRTV_{3,i}$ as the first seed**.

If

$$R < BRKTV_{3,i} \quad (4.4)$$

then the i th T.V. is assumed lost from our system. If equation (4.4) is not satisfied then the i th T.V. is allowed to reach

*The updated $INBRTV_{2,i}$ are used as the seeds of subsequent generations.

**The updated $INBRTV_{3,i}$ are used as the seeds of subsequent generations.

the ship unloading area in question and it is assumed that no breakdown has occurred in the part of the trip of the i th T.V. described above.

Before the i th T.V. is allowed to reach W.A.II from the appropriate ship unloading area, a random number, R , is generated from the appropriate distribution, as dictated by $IDBRTV_{4,i}$, utilizing $INBRTV_{4,i}$ as the first seed*.

$$\text{If } R < BRKTV_{4,i} \quad (4.5)$$

then the i th T.V. is assumed lost from our system. If equation (4.5) is not satisfied, then the i th T.V. is allowed to enter W.A.II and it is assumed that no breakdown has occurred in the part of the trip of the i th T.V. described above.

Before the i th T.V. is allowed to depart from W.A.II, a random number, R , is generated from the appropriate distribution, as dictated by $IDBRTV_{5,i}$, utilizing $INBRTV_{5,i}$ as the first seed**.

$$\text{If } R < \frac{TTVP_{6,i}}{WT2MAX} * BRKTV_{5,i} \quad (4.6)$$

where $TTVP_{6,i}$ = total waiting time of the i th T.V. in W.A.II in this trip of the i th T.V.

$$\text{if } TTVP_{6,i} < WT2MAX \quad (4.7)$$

$$\text{or if } R < BRKTV_{5,i} \quad (4.6)$$

$$\text{if } TTVP_{6,i} \geq WT2MAX \quad (4.7)$$

*The updated $INBRTV_{4,i}$ are used as the seeds of subsequent generations.

**The updated $INBRTV_{5,i}$ are used as the seeds of subsequent generations.

then the i th T.V. is assumed lost from our system. If equation (4.6) is not satisfied, then the i th T.V. is allowed to depart from W.A.II for the appropriate beach unloading area and it is assumed that no breakdown has occurred while the T.V. in question was waiting in W.A.II.

Before the i th T.V. is allowed to reach the appropriate beach unloading area from W.A.II, a random number, R , is generated from the appropriate distribution, as dictated by $IDBRTV_{6,i}$, utilizing $INBRTV_{6,i}$ as the first seed*. If

$$R < BRKTV_{6,i} \quad (4.8)$$

then the i th T.V. is assumed lost from our system. If equation (4.8) is not satisfied, then the i th T.V. is allowed to reach the beach unloading area in question and it is assumed that no breakdown has occurred in the part of the trip of the i th T.V. described above.

Before the i th T.V. is allowed to reach W.A.I from the appropriate beach unloading area, a random number, R , is generated from the appropriate distribution, as dictated by $IDBRTV_{7,i}$, utilizing $INBRTV_{7,i}$ as the first seed**. If

$$R < BRKTV_{7,i} \quad (4.9)$$

* The updated $INBRTV_{6,i}$ are used as the seeds of subsequent generations.

**The updated $INBRTV_{7,i}$ are used as the seeds of subsequent generations.

then the i th T.V. is assumed lost from our system. If equation (4.9) is not satisfied, then the i th T.V. is allowed to reach W.A.I and it is assumed that no breakdown has occurred in the part of the trip of the i th T.V. described above.

In our mathematical model the action taken as described above is forfeited for all the T.V. that happen to be in W.A.I immediately after the appropriate T.V. departed from W.A.I to load the last payload unit(s) from the Mother Ship. All these T.V. are assumed to have started for their respective bases at the times when they last started the execution of Step 12 given in the mission of the i th ($i = 1, 2 \dots I$) T.V.

Before the i th T.V. is allowed to reach its base from the appropriate beach unloading area, a random number, R , is generated from the appropriate distribution, as dictated by $IDBRTV_{g,i}$, utilizing $INBRTV_{g,i}$ as the first seed*. If

$$R < BRKTV_{g,i} \quad (4.10)$$

then the i th T.V. is assumed lost from our system. If equation (4.10) is not satisfied, then the i th T.V. is allowed to reach its base and it is assumed that no breakdown has occurred in the part of the journey of the i th T.V. described above.

* The updated $INBRTV_{g,i}$ are used as the seeds of subsequent generations.

vii) The Unloading Strategy of the Payload Units.

The payload units are first separated into K groups of N_k ($k = 1, 2, \dots, K$) units each. Next, the payload units of the first group are identified by distinct and ascending numbers. The numbers start from 1 and finish at N_1 . Then the payload units of the second group are similarly identified by numbers starting from $(1+N_1)$ to (N_1+N_2) . In the same manner, the payload units of the k th group are identified by numbers from $\left(1 + \sum_{j=1}^{k-1} N_j\right)$ to $\left(\sum_{j=1}^k N_j\right)$ and so on, until the last payload unit of the last group is identified as the $\left(\sum_{j=1}^K N_j\right)$ th payload unit. Once the above mentioned identification is complete, the payload units are loaded into the Mother Ship in the following manner. For each group*, the payload unit with the smallest identification number is loaded first into the appropriate location in the Mother Ship. After that, the j_k th payload unit of each of the K groups is loaded immediately after the (j_k-1) th payload unit of the same group into the appropriate location in the Mother Ship, where $2 + \sum_{j=1}^{k-1} N_j \leq j_k \leq \sum_{j=1}^k N_j$. This operation continues until all payload units have been loaded into the Mother Ship.

*Note that the loading operations of each of the K groups are totally independent of one another. The only point of interest to us is the loading order of the payload units of each of the K groups.

The unloading strategy we adopted for this study is the following. The payload units of each of the K groups* are to be unloaded in the exact reverse of the order in which they were loaded into the Mother Ship. Also, the payload units are to be unloaded at the beach in the exact reverse of the order in which they were loaded in the T.V. in question.

*The unloading sequences of each of the K groups are totally independent of one another.

viii) T.V. Use Strategy A for W.A.I.

This use strategy (see subroutine *ASLTVA*) is the first of the strategies incorporated in the mathematical model for selecting T.V. from W.A.I. It is basically a first come, first served strategy and is oriented towards volume-limited T.V. The T.V. selection is governed by the following rules:

1. First come, first selected*. In the event of a tie select the
2. T.V. with the biggest (available volume/time)**. In the event of a further tie select the
3. T.V. with the biggest (available weight capacity/time)***. In the event of a further tie select the
4. T.V. with the biggest available volume. In the event of a further tie select the
5. T.V. with the biggest available weight capacity. In the event of a further tie select the
6. Speedier**** T.V. In the event of a further tie select the
7. T.V. with the smallest identification.

*Not necessarily in effect if the T.V. selected cannot be serviced immediately. All T.V. available in W.A.I before the appropriate ship unloading area is free are equally eligible as far as the first rule is concerned.

**Available volume specified by $AMAXTV_{7,i}$ ($i=1,2\dots I$), time as measured by $(TTV_{4,i} + TTV_{10,i} + TTV_{11,i}; i=1,2\dots I)$.

***Available weight capacity specified by $AMAXTV_{6,i}$ ($i=1,2\dots I$)

****Speed measured by the above mentioned time, noting that the smaller $(TTV_{4,i} + TTV_{10,i} + TTV_{11,i}; i=1,2\dots I)$, then the speedier the T.V. is.

ix) T.V. Use Strategy B for W.A.I.

This use strategy (see subroutine *ASLTVB*) is the second of the strategies incorporated in the mathematical model for selecting T.V. from W.A.I.

It is again basically a first come, first served strategy but is oriented towards weight-limited T.V.

The T.V. selection is governed by the same rules given for the T.V. use strategy *A* for W.A.I, with the exception that the second rule is interchanged with the third, and the fourth with the fifth.

It is of interest to note that the user may make the most efficient use of the strategies *A* and *B* for W.A.I given above in the cases of mixed cargo (bulky and dense material) by specifying *IWA1SL=1* and *ICHANG=2*. This is so because the user will employ use strategy *A* for W.A.I for the initial stages of the operation, this being the more efficient strategy because the bulky cargo is usually stowed high in the ship's hold. At the final stages of the operation, as the material becomes denser, the algorithm automatically utilizes strategy *B* for W.A.I, this strategy being more efficient because it employs the T.V. in a more efficient manner.

x) T.V. Use Strategy C for W.A.I

86.

This use strategy (see subroutine *ASLTVC*) is the third of the strategies incorporated into the mathematical model for selecting T.V. from W.A.I.

It is again basically a first come, first served strategy, oriented towards volume-limited T.V., but with provisions to permit the minimum number of T.V. refuellings. For this reason, this use strategy is superior to use strategy *A* for W.A.I in situations where a large number of T.V. refuellings is expected.

The T.V. selection is governed by the same rules as those given for the T.V. use strategy *A* for W.A.I, with an additional rule (inserted immediately before the 7th rule) allowing the selection of the T.V. which can execute the most round trips, at the time of selection, without refuelling. As before, in the event of a tie the T.V. with the smallest identification is selected.

This use strategy (see subroutine *ASLTVD*) is the fourth of the strategies incorporated into the mathematical model for selecting T.V. from W.A.I.

It is again basically a first come, first served strategy, oriented towards weight-limited T.V., but with provisions to permit the minimum number of T.V. refuellings. For this reason, this use strategy is superior to use strategy *B* for W.A.I in situations where a large number of T.V. refuellings is expected.

The T.V. selection is governed by the same rules given for the T.V. use strategy *B* for W.A.I, with an additional rule (inserted immediately before the 7th rule) allowing the selection of the T.V. which can execute the most round trips, at the time of selection, without refuelling. As before, in the event of a tie the T.V. with the smallest identification is selected.

As was noted earlier, and for the same reasons, the user may make the most efficient use of the above strategies *C* and *D* for W.A.I in the cases of mixed cargo (bulky and dense material) by specifying *IWA1SL=3* and *ICHANG=2*.

This use strategy (see subroutine *ASLTVE*) is the fifth and last of the strategies incorporated into the mathematical model for selecting T.V. from W.A.I. It is basically a first come, first served strategy but with provisions to permit the best utility of T.V. available in W.A.I at the time of decision. For this reason, this strategy is expected to be superior to all other use strategies for W.A.I mentioned earlier, but it is also expected to be the most difficult to implement. For this reason the user should employ this strategy only when there is a high probability (a very strong function of both the environment's state and the conditions of operation) of being implemented in practice.

The T.V. selection is governed by the following rules.

a) When *IWA1SL* = 5

1. Select a T.V. with the rules given by *ASLTVA*.
2. Retain this selection if the T.V. so selected can be serviced immediately; otherwise reject this choice and select from among the T.V. available in W.A.I at the time of the decision (i.e., when the appropriate S.U.F. becomes available) the T.V. with the highest utility factor*. In the event of a tie select the
3. T.V. with the smallest identification.

b) When *IWA1SL* = 6

Obtain the original T.V. selection using the rules given by *ASLTVB*.

*Utility Factor =

$$\frac{\text{Utilized T.V. Volume Capacity}}{\text{Available T.V. Volume Capacity}} + \frac{\text{Utilized T.V. Weight Capacity}}{\text{Available T.V. Weight Capacity}}$$

c) When $IWA1SL = 7$

89.

Obtain the original T.V. selection using the rules given by *ASLTVC*.

d) When $IWA1SL = 8$

Obtain the original T.V. selection using the rules given by *ASLTVD*.

Please note that in this version of the program, *ICHANG* can only be set equal to 1, and no provision is made for the original selection to change automatically from a weight-limited to a volume-limited oriented use strategy or vice versa, as this was not considered necessary.

xiii) T.V. Use Strategy A for W.A.II.

This use strategy (see subroutine *BSLTVA*) is the first of the strategies incorporated into the mathematical model for selecting T.V. from W.A.II*. It is basically a first come, first served strategy and is oriented towards volume-limited T.V. (For this reason, it is logical that this use strategy should be employed for the T.V. selection from W.A.II when use strategy A for W.A.I is employed to select T.V. from W.A.I.)

The T.V. selection is governed by the following rules:

1. First come, first selected**. In the event of a tie select the
2. T.V. with the biggest (available volume/time)***. In the event of a further tie select the
3. T.V. with the biggest (available weight capacity/time)****. In the event of a further tie select the
4. T.V. with the biggest available volume. In the event of a further tie select the
5. T.V. with the biggest available weight capacity. In the event of a further tie select the

*The T.V. selected from W.A.I is retained until a T.V. is available at an earlier time in W.A.II.

**Not necessarily in effect if the T.V. selected cannot be serviced immediately. All T.V. available in W.A.II before the appropriate beach unloading area is free are equally eligible as far as the first rule is concerned.

***Available volume specified by $AMAXTV_{7,i}$ ($i=1,2\dots I$), time as measured by $(TTV_{13,i} + TTV_{15,i} + TTV_{16,i}; i=1,2\dots I)$.

****Available weight capacity specified by $AMAXTV_{6,i}$ ($i=1,2\dots I$).

6. T.V. with the biggest (utilized volume/time)*. In the event of a further tie select the
7. T.V. with the biggest (utilized weight capacity/time)**. In the event of a further tie select the
8. T.V. with the biggest utilized volume. In the event of a further tie select the
9. T.V. with the biggest utilized weight capacity. In the event of a further tie select the
10. Speedier*** T.V. In the event of a further tie select the
11. T.V. with the smallest identification.

*Utilized volume is measured by summing up the volume of each payload unit and its lashings carried by the T.V. in question in that particular trip, time as measured by $(TTV_{13,i} + TTV_{15,i} + TTV_{16,i}; i=1,2...I)$.

**Utilized weight capacity is measured by summing up the weight of each payload unit and its lashings carried by the T.V. in question in that particular trip.

***Speed measured by the above mentioned time, noting that the smaller $(TTV_{13,i} + TTV_{15,i} + TTV_{16,i})$, then the speedier the T.V. is.

xiv) T.V. Use Strategy B for W.A.II.

This use strategy (see subroutine *BSLTVB*) is the second of the strategies incorporated into the mathematical model for selecting T.V. from W.A.II*.

It is again basically a first come, first served strategy but is oriented towards weight-limited T.V. (For this reason, it is logical that this use strategy should be employed for the T.V. selection from W.A.II when use strategy *B* for W.A.I is employed to select T.V. from W.A.I.)

The T.V. selection is governed by the same rules given for the T.V. use strategy *A* for W.A.II with the exception that the second rule is interchanged with the third, the fourth with the fifth, the sixth with the seventh, and the eighth with the ninth.

In the same way as was noted when discussing the use strategies for W.A.I, and for the same reasons, the user may make the most efficient use of the above strategies *A* and *B* for W.A.II in the cases of mixed cargo (bulky and dense material) by specifying *IWA2SL=1* and *ICHANG=2*.

*The T.V. selected from W.A.I is retained until a T.V. is available at an earlier time in W.A.II.

This use strategy (see subroutine *BSLTVC*) is the third of the strategies incorporated into the mathematical model for selecting T.V. from W.A.II*.

It is again basically a first come, first served strategy oriented towards volume-limited T.V., but with provisions to permit the minimum number of T.V. refuellings**. For this reason, this use strategy is superior to use strategy A for W.A.II in situations where a large number of T.V. refuellings is expected.

The T.V. selection is governed by the same rules as those given for the T.V. use strategy A for W.A. II, with an additional rule (inserted immediately before the 11th rule) allowing the selection of the T.V. which can execute the most round trips, at the time of selection, without refuelling. As before, in the event of a tie the T.V. with the smallest identification is selected.

*The T.V. selected from W.A.I is retained until a T.V. is available at an earlier time in W.A.II.

**It is logical that this use strategy should be employed for the T.V. selection from W.A.II when use strategy C for W.A.I is employed to select T.V. from W.A.I.

This use strategy (see subroutine *BSLTVD*) is the fourth and last of the strategies incorporated into the mathematical model for selecting T.V. from W.A.II*.

It is again basically a first come, first served strategy oriented towards weight-limited T.V. but with provisions to permit the minimum number of T.V. refuellings**. For this reason, this use strategy is superior to use strategy *B* for W.A.II in situations where a large number of T.V. refuellings is expected.

The T.V. selection is governed by the same rules given for the T.V. use strategy *B* for W.A.II, with an additional rule (inserted immediately before the 11th rule) allowing the selection of the T.V. which can execute the most round trips, at the time of selection, without refuelling. As before, in the event of a tie the T.V. with the smallest identification is selected.

As was noted earlier, and for the same reasons, the user may make the most efficient use of the above strategies *C* and *D* for W.A.II in the cases of mixed cargo (bulky and dense material) by specifying *IWA2SL=3* and *ICHANG=2*.

*The T.V. selected from W.A.I is retained until a T.V. is available at an earlier time in W.A.II.

**It is logical that this use strategy should be employed for the T.V. selection from W.A.II when use strategy *D* is employed to select T.V. from W.A.I.

xvii) S.U.F. Use Strategy A

This use strategy (see subroutine *SLSCA*) is the first of the strategies incorporated into the mathematical model for selecting S.U.F. It is a first come, first served strategy. The S.U.F. selection is governed by the following rules:

1. The S.U.F. whose associated ship unloading area is first free is first selected. In the event of a tie, select the
2. S.U.F. that has the most cargo to unload at the time the above mentioned tie occurred. In the event of a further tie select the
3. S.U.F. that will be ready to commence its unloading cycle first*. In the event of a further tie select the
4. Speedier** S.U.F. In the event of a further tie select the
5. S.U.F. with the smallest identification.

*A. S.U.F. is ready to commence its unloading cycle at the instant it reaches the ship unloading area associated with it for the first time or at any other time immediately after the S.U.F. in question is made ready to travel again after it has unloaded the appropriate payload unit into the appropriate T.V.

**Speed measured by the time ($TSC_{2,k} + TSC_{3,k} + TSC_{4,k} + TSC_{5,k} + TSC_{7,k}$; $k=1,2,\dots,K$), noting that the smaller this time, then the speedier the S.U.F. is.

This use strategy (see subroutine *SLSCB*) is the second of the strategies incorporated into the mathematical model for selecting S.U.F. It is basically a first come, first served strategy.

The S.U.F. selection is governed by the same rules given for S.U.F. use strategy *A*, with the exception that Rules 1 and 3 are not necessarily in effect if the S.U.F. has to await the arrival of a T.V. in W.A.I. In that case, all S.U.F. whose associated ship unloading areas are free and are ready to commence their unloading cycles before the arrival of the T.V. in question in W.A.I are equally eligible regarding the first and third rules.

This use strategy is expected to be more efficient than S.U.F. use strategy *A* in most cases, as it guarantees a more uniform unloading of the ship's cargo from different holds, which in turn implies minimum closure time. This, however, is expected to be slightly more difficult to implement than S.U.F. use strategy *A*, as it requires a continuous inventory of the holdings of each hold.

This use strategy (see subroutine *SLSCC*) is the third and last of the strategies incorporated into the mathematical model for selecting S.U.F. It is basically a first come, first served strategy but with provisions to maximize the utility factor* of the T.V. available in W.A.I at the time of the decision. This use strategy is comparable to S.U.F. use strategy *B* because although it allows the most efficient use of the T.V. it also allows the unloading of the ship's cargo from different holds to become non-uniform, which in turn implies a large closure time in most cases. In addition, as in the case of *ASLTVE*, the *SLSCC* is expected to be a more difficult strategy to implement than were *SLSCA* or *SLSCB*. For this reason, the user should employ this strategy only when there is a high probability (a very strong function of both the environment's state and the conditions of operation) of being implemented in practice.

The S.U.F. selection is governed by the following rules.

1. Select a S.U.F. with the rules given by *SLSCB*.
2. Retain this selection if there is a T.V. in W.A.I that can be serviced immediately; otherwise reject this choice and select from among the S.U.F. available at the time of the decision (i.e., when the appropriate T.V. reaches W.A.I) the S.U.F. which can maximize the utility factor* of the T.V. in question. In the event of a tie select the
3. S.U.F. with the smallest identification.

$$\text{*Utility factor} = \frac{\text{Utilized T.V. Volume Capacity}}{\text{Available T.V. Volume Capacity}} + \frac{\text{Utilized T.V. Weight Capacity}}{\text{Available T.V. Volume Capacity}}$$

xx) B.U.F. Use Strategy A.

This use strategy (see subroutine *SLBCA*) is the first of the strategies incorporated into the mathematical model for selecting B.U.F. It is a first come, first served strategy. The B.U.F. selection is governed by the following rules:

1. The B.U.F. whose associated beach unloading area is first free is first selected. In the event of a tie select the
2. B.U.F. that will be ready to commence its unloading cycle first*. In the event of a further tie select the
3. Speedier** B.U.F. In the event of a further tie select the
4. B.U.F. with the smallest identification.

*B.U.F. is ready to commence its unloading cycle at the instant it is made ready for travel after it has reached point A on the beach for the first time or, at any other time, after the appropriate payload unit has been released at point A on the beach and the B.U.F. has been made ready to travel again.

**Speed measured by the time ($TBC_{4,\ell} + TBC_{6,\ell} + TBC_{7,\ell} + TBC_{8,\ell}$; $\ell=1,2\dots L$) noting that the smaller the above mentioned time, then the speedier the B.U.F. is.

This use strategy (see subroutine *SLBCB*) is the second of the strategies incorporated into the mathematical model for selecting B.U.F. It is basically a first come, first served strategy.

The B.U.F. selection is governed by the same rules given for B.U.F. use strategy *A*, with the exception that Rules 1 and 2 are not necessarily in effect if the B.U.F. has to await the arrival of a T.V. in W.A.II. In that case, all B.U.F. whose associated beach unloading areas are free and are ready to commence their unloading cycles before the arrival of the T.V. in question in W.A.II are equally eligible regarding the first and second rules.

This strategy is expected to be more efficient than B.U.F. use strategy *A* in most cases, as it guarantees the utilization of the most efficient B.U.F., which in turn implies minimum closure time. This, however, is expected to be slightly more difficult to implement than B.U.F. use strategy *A*, as it requires a knowledge of the operational characteristics of all B.U.F.

The above completes our description of the formulation of the mathematical model for our study. We now proceed with a discussion of the solution method.

5. Solution Method

For the reasons given in Section 2, the method of digital simulation is selected to solve the problem under investigation. Because of the size of the problem, the use of digital computers is inevitable. The computer program for this method became most efficient when it was so structured that the main program served as a scheduler, passing control to the appropriate subroutine, which simulated the appropriate event at the time when control was passed. Collectively, the events simulate the entire mathematical model of our system. The definition of the events and of the scheduling mechanism used in our study is given below.

A) Event Definition

The events selected for our study are:

1.
 - i) The arrival and mooring of Mother Ship,
 - ii) The preparation of all S.U.F. for the unloading operation and their arrival at the appropriate ship unloading areas,
 - iii) The arrival of all B.U.F. at point A on the beach and their preparation for the unloading operation, and
 - iv) The arrival of all T.V. in W.A.I*.
2.
 - a) The selection of a T.V. from W.A.I, or
 - b) The selection of a T.V. from W.A.II.

*If there are any breakdown considerations involved in our investigation for this part of the trip of the T.V. in question, then they must be taken into account.

3. a) The selection of a S.U.F. or
b) The selection of a B.U.F.

4. a) The loading operation alongside the Mother Ship
comprising
 - i) Steps 2-4 of the mission of the i th ($i=1,2,\dots,I$) T.V.*
 - ii) Steps 2-6 of the mission of the k th ($k=1,2,\dots,K$)
S.U.F.**.
 - iii) Steps 5-7 of the mission of the i th ($i=1,2,\dots,I$) T.V.*or
b) The unloading operation at the beach comprising
 - i) Steps 8 and 9 of the mission of the i th ($i=1,2,\dots,I$)
T.V.*
 - ii) Steps 3-6 of the mission of the l th ($l=1,2,\dots,L$) B.U.F.
 - iii) Steps 10-12 of the mission of the i th ($i=1,2,\dots,I$)
T.V.*

5. The closing of the entire operation *** by executing
 - i) Event 2b,
 - ii) Event 3b,

* If there are any breakdown considerations involved in our investigation for this (these) part(s) of the trip of the T.V. in question, then they must be taken into account.

**Please note that as soon as the k th ($k=1,2,\dots,K$) S.U.F. unloads its entire payload, step 7 of the mission of the k th ($k=1,2,\dots,K$) S.U.F. is executed for the S.U.F. in question.

***This event is executed only when there are no more payload units to be unloaded from the Mother Ship.

- iii) Steps 8 and 9 of the mission of the i th ($i=1,2\dots I$) T.V.* for all T.V. in W.A.II,
- iv) Steps 3-6 of the mission of the l th ($l=1,2\dots L$) B.U.F.,
- v) Steps 10 and 11 of the mission of the i th ($i=1,2\dots I$) T.V.* for all T.V. in W.A.II,
- vi) Step 3 of the mission of the Mother Ship,
- vii) Steps 7 and 8 of the mission of the l th ($l=1,2\dots L$) B.U.F., and
- viii) Step 13** of the mission of the i th ($i=1,2\dots I$) T.V.*

B) Scheduling Mechanism Definition

The considerations leading to the definition of the scheduling mechanism that is to be used by the main program for scheduling the appropriate event at any given time are given below.

At the outset of our investigation it was found essential that our model should be provided with a simulation clock, which is to be used to record the start of an event execution, as this information was considered to be useful output. Next,

*If there are any breakdown considerations involved in our investigation for this part of the trip of the T.V. in question, then they must be taken into account.

**The action taken by executing step 12 of the mission of the i th ($i=1,2\dots I$) T.V. is forfeited for all the T.V. that are in W.A.I when the execution of the fifth event commences.

it was noted that as our simulation is event structured, the simulation clock could also be used as the scheduling mechanism if

- i) at the start of the entire operation the clock was initialized to a zero reference time,
- ii) at subsequent times the clock was always updated to show the starting time of the last event executed, and
- iii) the time at which an event is terminated is continuously updated.

This is so because we may now schedule the next event correctly by simply selecting the earliest available event after that just executed, as recorded by the simulation clock. The above description defines the scheduling mechanism employed in this study for scheduling the event that is to be executed at any given time.

In our mathematical model, once the correct event is decided by using the above mentioned method, the action taken is as follows:

Control is passed to the appropriate subroutine, which executes the event in question, updates all the relevant variables and the simulation clock, and then returns control to the scheduler, which repeats the above procedure until the fifth event is executed, terminating the analysis of the run under investigation.

From the above, it follows that because the simulation clock advances only in discrete jumps (including the zero jump), then we may collect any information relevant to the problem by examining the simulation only at the discrete times recorded by the simulation clock. This is so because no event may start at any other time, and as the entire simulation is represented by events, no additional information may be obtained by examining the simulation more frequently.

The above discussion completes our description of the event structure of our mathematical model and the scheduling mechanism, the two most important aspects of our method. All other aspects of our method, such as random number generation, tests for random number generators, etc., are not covered here as their treatment may be found elsewhere.

To permit the reader to fully understand the simulation process, a brief description of the computer program is given below, together with a general flow chart*, which will also serve to show the reader how to introduce new use strategies when this is found desirable.

* For the sake of simplicity of presentation, the general flow chart does not include the breakdown considerations.

MAIN

The MAIN program in our simulation serves as a scheduler, and operates as follows:

1. Reads the input specifying the number of cases to be processed by this computer run.
2. Passes control to Subroutine INPUT to read the input of the case under investigation.
3. Passes control to Subroutine INOUT to print the input of the case under investigation.
4. Initializes the model.
5. Passes control to Subroutine BEGIN to simulate the arrival of our resources in the theatre of operations.
6. Passes control to the appropriate Subroutine for selecting a T.V. from W.A.I which in turn passes control to the appropriate Subroutine for selecting a T.V. from W.A.II, if such a T.V. is available at an earlier time than the one already selected in W.A.I.
7. Passes control to the appropriate Subroutine for selecting a S.U.F. or to the appropriate Subroutine for selecting a B.U.F., depending upon the outcome of the above step.
8. Passes control to Subroutine LOAD or UNLOAD, depending upon the outcome of the two steps just mentioned.
9. Passes control to Subroutine FIN, which in turn passes control to the appropriate Subroutines for selecting T.V. from W.A.II and B.U.F. from the beach, until all T.V. in W.A.II

are processed. Subroutine FIN then simulates the departure of our resources from the theatre of operations at the conclusion of our mission.

10. Punches out the desired input of program STATIC, which is used to compute the necessary statistics, and finally,
11. If more runs are to be executed for the case under investigation, steps 4-10 given above are repeated until the number of runs executed is equal to that prespecified, in which case the analysis of the case under investigation terminates.

It should be noted that the program is so arranged as to permit (by repeating steps 2-11 given above) the processing of as many cases as is desired by simply providing the necessary input information. In addition, it should be noted that during the execution of any run, as soon as all transfer vehicles are found to be malfunctioning, the processing of this run is terminated and the processing of the next one (if any) is automatically started.

INPUT

This Subroutine reads all the input pertaining to the case under investigation.

The input for each case comprises:

1. The specification of the number of runs.
2. The specification of the units of the variables.

3. The specification of the variables defining the payload characteristics and its allocation.
4. The specification of the variables defining the Mother Ship characteristics.
5. The specification of the variables defining the S.U.F., the B.U.F. and the T.V.

In addition, the input specifies a) the loading mode at the Mother Ship, b) the unloading mode at the beach, c) the use strategies to be used at each of the decision nodes, and d) whether or not a change in the use strategy specified by the user is permitted during the execution of the run. Furthermore, the input specifies whether a process is deterministic or stochastic. If the process is stochastic, the input designates the type of random number generator to be used, its seed, and the range of variation of the random numbers. Finally, the input indicates whether malfunctioning considerations are to be included in our analysis and, if so, supplies the necessary information.

INOUT

This Subroutine prints out all the input pertaining to the case under investigation in such a manner as to permit easy reference to such information.

RANDU

This Subroutine computes uniformly distributed random real

numbers between zero and one. It is of the congruential type and is identical to the subroutine listed in IBM's Scientific Subroutine Package*. With a starting value (seed) that satisfies the requirements set out in the above mentioned reference, it has a cycle length of 2^{29} terms and it satisfies all the usual tests for randomness.

BEGIN

This Subroutine simulates the first event, described at the beginning of this section. If any breakdown considerations are to be included in this investigation for this part of the simulation, all T.V. found to be malfunctioning are refused entry into W.A.I.

ASLTVA, ASLTVB, ASLTVC, ASLTVD and ASLTVE

These Subroutines define all the strategies incorporated into the model for selecting T.V. from W.A.I**. The rules utilized by the above mentioned Subroutines for the T.V. selection from W.A.I have already been given in Section 4 (see T.V. use strategies A, B, C, D and E for W.A.I).

BSLTVA, BSLTVB, BSLTVC and BSLTVD

These Subroutines define all the strategies incorporated into the model for selecting T.V. from W.A.II***. The rules

*See the bibliography at the end of this report.

**Compare with event 2a, described at the beginning of this section.

***Compare with event 2b, described at the beginning of this section.

utilized by the above mentioned Subroutines for the T.V. selection from W.A.II have already been given in Section 4 (see T.V. use strategies A, B, C and D for W.A.II).

SLSCA, SLSCB and SLSCC

These Subroutines define all the strategies incorporated into the model for selecting S.U.F.* The rules utilized by the above mentioned Subroutines for the S.U.F. selection have already been given in Section 4 (see S.U.F. use strategies A, B and C).

LOAD

This Subroutine simulates event 4a, described at the beginning of this section. If any breakdown considerations are to be included in this investigation for this part of the simulation, all T.V. found to be malfunctioning are refused departure from W.A.I, arrival at the ship unloading area in question, or entry into W.A.II, depending upon where the breakdown occurred.

SLBCA and SLBCB

These Subroutines define all the strategies incorporated into the model for selecting B.U.F.** The rules utilized by

*Compare with event 3a, described at the beginning of this section.

**Compare with event 3b, described at the beginning of this section.

the above mentioned Subroutines for the B.U.F. selection have ^{110.} already been given in Section 4 (see B.U.F. use strategies A and B).

UNLOAD

This Subroutine simulates event 4b, described at the beginning of this section. If any breakdown considerations are to be included in this investigation for this part of the simulation, all T.V. found malfunctioning are refused departure from W.A.II, arrival at the beach unloading area in question, or entry into W.A.I, depending upon where the breakdown occurred.

FIN

This Subroutine simulates the fifth event, described at the beginning of this section. If any breakdown considerations are to be included in this investigation for this part of the simulation, all T.V. found malfunctioning are refused departure from W.A.II, arrival at the beach unloading area in question, or arrival at their bases, depending upon where the breakdown occurred.

STATIC

This is an independent program which allows the user to compute the statistical properties of the output obtained from the main program. This computation involves (a) the calculation of the mean and variance of two streams of observations*

*STATIC is limited in that it can process only 8 pairs of streams and 500 observations per stream at any one time, which was found more than adequate in our study.

when the two streams are treated as independent, and (b) the calculation of the mean, covariance, variance and efficiency (see part E of Section 5) of the same two streams of observations when the two streams are treated as dependent.

It should be noted that no provisions have been made for the automatic computation of c (the figure of merit) of equation (3.17), for the reasons given at the conclusion of Section 3.

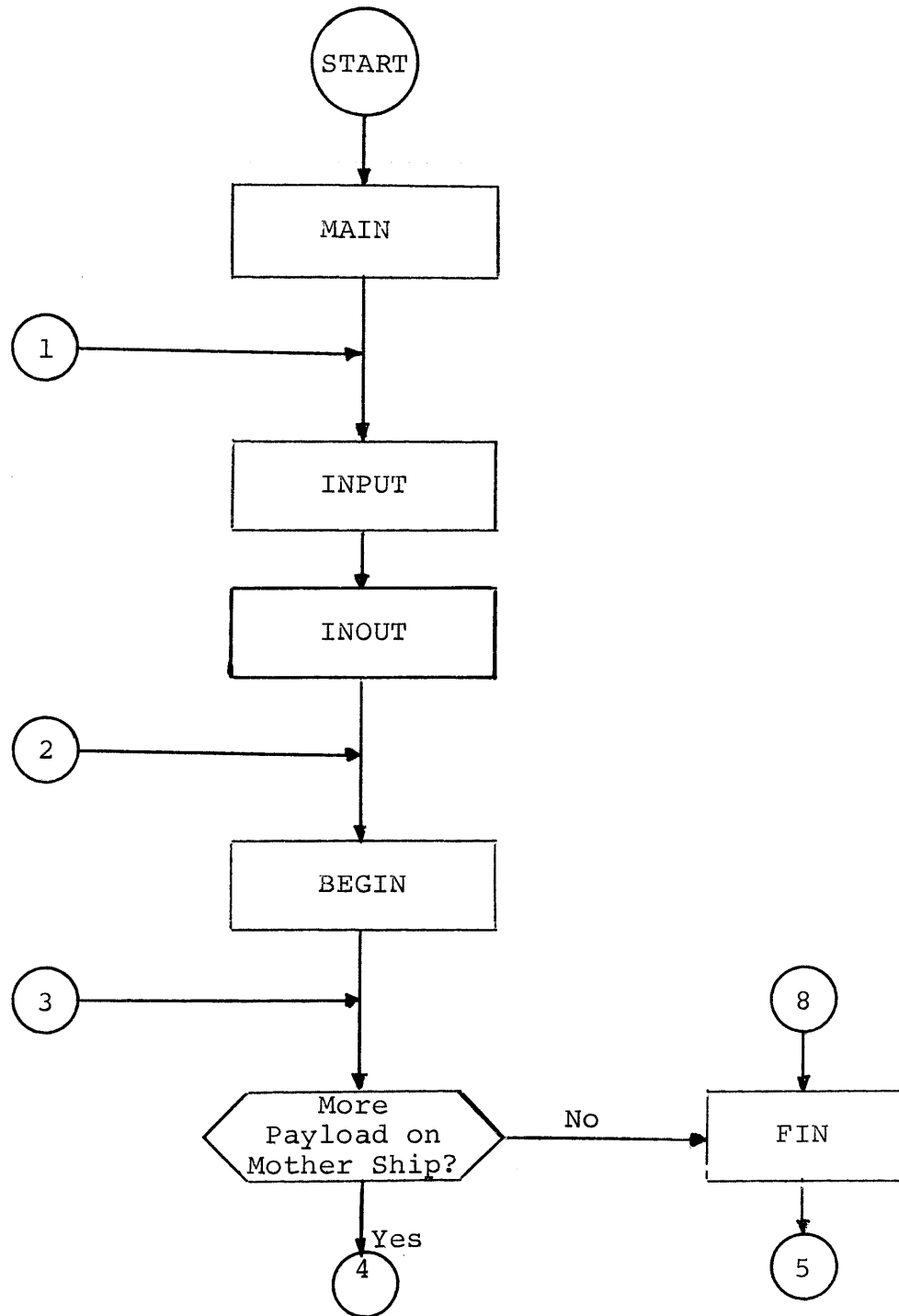


Fig. 5-1a. General Flow Chart

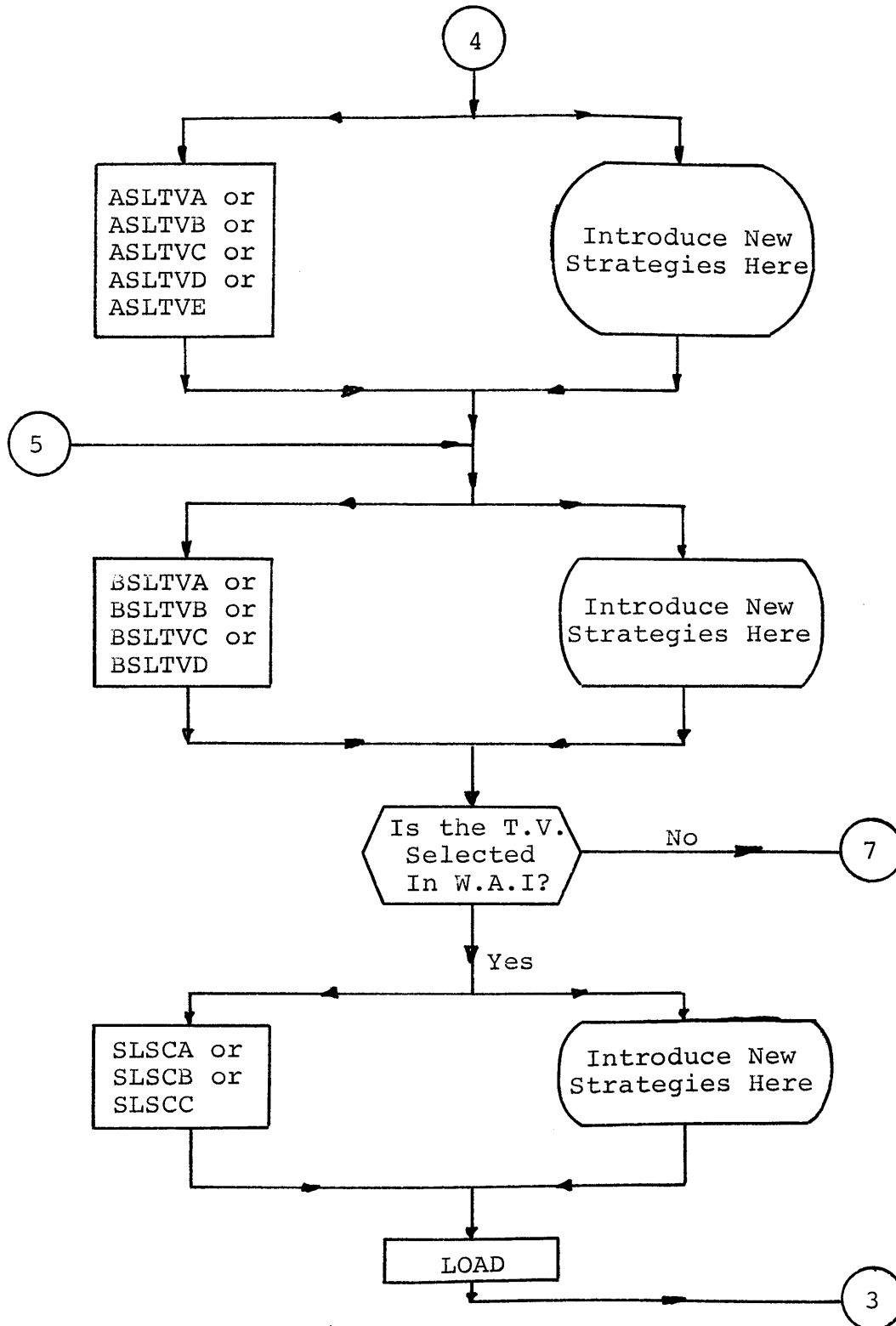


Fig. 5-1a (continued)
General Flow Chart

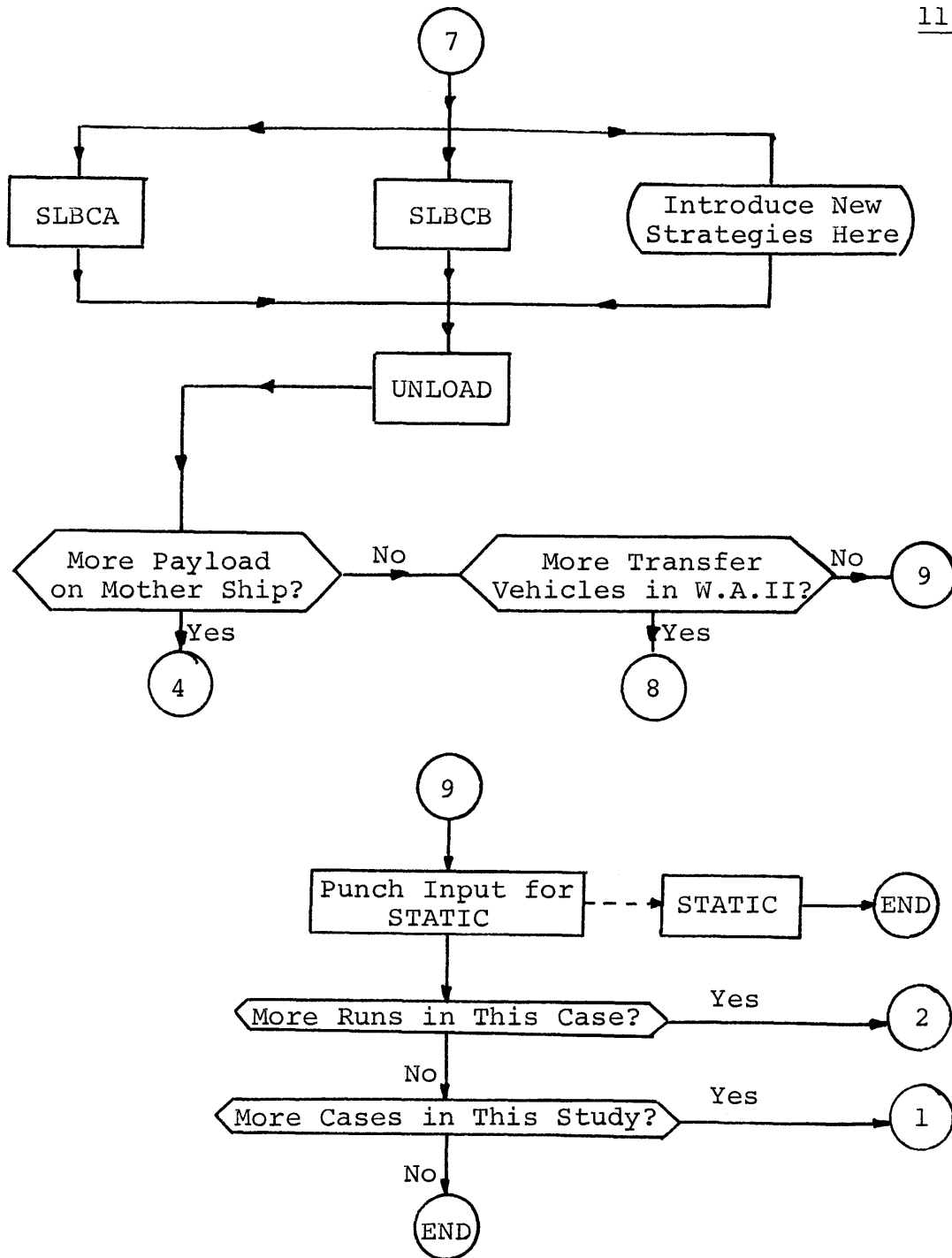


Fig. 5-1a (continued)
General Flow Chart

E. Concept of Antithetic Variance

As was noted earlier in this section, the method of digital simulation was selected to solve the problem under investigation. For a more detailed discussion on the selection of the solution method, the reader is referred to Section 2.

The additional* disadvantage introduced into our methodology by adopting digital simulation as the solution method is, of course, expense. This is so because in order to obtain reliable results when simulating, it becomes necessary to exercise the underlying mathematical model many times in order to obtain reliable results in the statistical sense. Because the mathematical model is large, the expense of a complete analysis might have become prohibitive, and so with this motivation, a literature search was conducted in an attempt to find a method that would make the solution process more economical. In other words, the author was seeking a method enabling him to exercise the underlying mathematical model the minimum number of times in order to estimate the necessary results with a prespecified degree of confidence.

The literature search revealed that no such method was available for direct use. This search, however, revealed allusions to a method (Antithetic Variance) which, if

*As was noted in Section 2 by adopting digital simulation our solution is limited in being the best alternative among the ones examined.

successful, would offer the desired effects. Unfortunately, no detailed work was ever reported even on the simplest form that our mathematical model can take (1 Queue 1 Server system), let alone on a model of any complexity such as the mathematical model of our study. Guided by the scanty results available, the author anticipated favorable end results of such a method even when applied to complex congestion models such as ours, and so he embarked on a detailed analysis of such a method. The results of this analysis are presented in the remainder of this section.

i) Justification of the Introduction of the Concept of Antithetic Variance in the Monte Carlo Techniques.

Let us assume that we wish to estimate the mean, μ_a , and variance, σ_a^2 , of a stochastic variable a , whose mean and variance cannot be determined analytically. Usually, in this case one of the most convenient methods for estimating μ_a and σ_a^2 is to construct a model which simulates the behavior of the physical system whose output is the stochastic variable a , and then exercise the model and observe the resulting values α_j ($j=1, 2, \dots, 2n$) of the variable in question. Then, using the α_j 's, an estimate on μ_a and σ_a^2 can be obtained by employing the standard methods described in any text book on statistics (e.g. Mode, for complete title see bibliography).

However, if we view the stream of observations α_j in the manner described below, we can make an interesting observation.

Assume that the stream of α_j ($j=1,2,\dots,2n$) observations is separated into two streams of observations β_i' and β_i'' ($i=1,2,\dots,n$), and we define a variable β_i ($i=1,2,\dots,n$) such that

$$\beta_i = \frac{1}{2}(\beta_i' + \beta_i'') \quad (i=1,2,\dots,n) \quad (5.1)$$

then it follows that β_i can also be used to provide an estimate on μ_α and σ_α^2 in the following manner.

$$\hat{\mu}_\alpha = \mu_\beta = \frac{1}{2n} \sum_{i=1}^n (\beta_i' + \beta_i'') = \frac{1}{2}(\mu_{\beta'} + \mu_{\beta''}) \quad (5.2)$$

$$\text{where } \mu_{\beta'} = \frac{1}{n} \sum_{i=1}^n \beta_i' \quad (5.3)$$

$$\mu_{\beta''} = \frac{1}{n} \sum_{i=1}^n \beta_i'' \quad (5.4)$$

and $\hat{\mu}_\alpha$ is an unbiased estimator of μ_α

$$\hat{\sigma}_\alpha^2 = \sigma_\beta^2 = \frac{1}{n-1} \sum_{i=1}^n (\beta_i - \mu_\beta)^2 = \frac{1}{4} \left[\sigma_{\beta'}^2 + \sigma_{\beta''}^2 + \frac{2n}{n-1} \text{cov}(\beta', \beta'') \right] \quad (5.5)$$

$$\text{where } \sigma_{\beta'}^2 = \frac{1}{n-1} \sum_{i=1}^n (\beta_i' - \mu_{\beta'})^2 \quad (5.6)$$

$$\sigma_{\beta''}^2 = \frac{1}{n-1} \sum_{i=1}^n (\beta_i'' - \mu_{\beta''})^2 \quad (5.7)$$

$\hat{\sigma}_\alpha^2$ is an unbiased estimator of σ_α^2

$$\text{and } \text{cov}(\beta', \beta'') = \frac{1}{n} \sum_{i=1}^n (\beta_i' - \mu_{\beta'}) (\beta_i'' - \mu_{\beta''}) \quad (5.8)$$

$$= E(\beta', \beta'') - E(\beta')E(\beta'') \quad (5.9)$$

where E stands for the expected value of the parenthesized quantity.

If β' and β'' are independent streams of observations (linear independence is sufficient), denoted here with a subscript, I , then the R.H.S. of equation (5.8) becomes identically equal to zero, as $E(\beta', \beta'') = E(\beta')E(\beta'')$ so equation (5.5) can be rewritten as follows:

$$\hat{\sigma}_a^2 = \sigma_{a_I}^2 = \frac{1}{4} \left(\sigma_{\beta'_I}^2 + \sigma_{\beta''_I}^2 \right) \quad (5.10)$$

However, if β' and β'' are dependent streams of observations, denoted here with a subscript, D , then equation (5.5) can be rewritten as follows:

$$\hat{\sigma}_a^2 = \sigma_{a_D}^2 = \frac{1}{4} \left[\sigma_{\beta'_D}^2 + \sigma_{\beta''_D}^2 + \frac{2n}{n-1} \text{cov}(\beta'_D, \beta''_D) \right] \quad (5.11)$$

Equations (5.10) and (5.11) allow us to make the following interesting observation. As it is reasonable to expect that

$$\sigma_{\beta'_I}^2 \approx \sigma_{\beta''_I}^2 \quad (5.12)$$

$$\text{and } \sigma_{\beta'_D}^2 \approx \sigma_{\beta''_D}^2 \quad (5.13)$$

as both relate to the same process, and n is assumed large (5.14)

and as $\sigma_{\beta'_I}^2$ can be made identically equal to $\sigma_{\beta'_D}^2$ then it follows that

$$\sigma_{a_D}^2 < \sigma_{a_I}^2 \quad (5.15)$$

if $\text{cov}(\beta'_D, \beta''_D) < 0$.

In other words, equation (5.15) suggests that using two streams of independent observations is less efficient than if the user employs two streams of dependent

observations of equal length, so arranged that they have 119. a negative covariance, because then μ_a is estimated with greater confidence (because the variance associated with our estimate is smaller). Putting this in another way, it is more efficient to obtain our estimate on μ_a from two streams of dependent observations arranged so as to have a negative covariance, than from two streams of independent observations, because we can then achieve the same level of confidence with fewer observations.

In order to provide a measure of success for our method the following variable was introduced:

$$Efficiency = \eta = \frac{\sigma_{\beta_I'}^2 + \sigma_{\beta_I''}^2}{\sigma_{\beta_D'}^2 + \sigma_{\beta_D''}^2 + \frac{2n}{n-1} cov(\beta_D', \beta_D'')} \quad (5.16)$$

It is of interest to study the behavior of equation (5.16) under some simplifying conditions in order to obtain an understanding in the behavior of η as a function of success in achieving different degrees of negative correlation.

If we substitute an equality sign in equations (5.12) and (5.13), then by using the modified equations (5.12) and (5.13) together with (5.14), equation (5.16) can be re-written as follows:

$$\eta = \frac{1}{1 + \frac{n}{n-1} r(\beta_D', \beta_D'')} \quad (5.17)$$

where $r(\beta_D', \beta_D'')$ is the correlation coefficient which by definition varies between -1 and +1.

(When $r(\beta'_D, \beta''_D) = -1$ we have perfect negative correlation,
 $= 0$ we have independent samples and
 $= 1$ we have perfect positive correlation)

For large n equation (5.17) can be rewritten as follows:

$$\eta = \frac{1}{1 + r(\beta'_D, \beta''_D)} \quad (5.18)$$

and from equation (5.18) it follows that as we increase the degree of negative correlation, the efficiency of the proposed scheme increases, and finally reaches the value of infinity, when perfect negative correlation is achieved.

From this, we may conclude that it is to our advantage to seek a method that will maximize the negative correlation between β' and β'' , as this will enhance the efficiency of our methodology.

ii) Development of the Method of Antithetic Variance for a One Queue-One Server (1Q-1S) Congestion System.

Consider a 1Q-1S system where x , a random number such that $x \geq 0$ drawn from a prespecified p.d.f. $F_x(x_0)$, represents the customer interarrival time, and y , a random number such that $y \geq 0$ drawn from a prespecified p.d.f. $G_y(y_0)$, represents the service time of each customer. Note also that x and y be totally independent of each other. From equation (A-6) of Appendix A it follows that we can express x and y as follows:

$$x = \phi(\xi) \quad (5.19)$$

$$y = \psi(\zeta) \quad (5.20)$$

where ξ and ζ are random variables drawn from a $U(0,1)$ p.d.f. (note that because x and y are independent, ξ and ζ must also be drawn independently).

From the above equations it follows that ξ and x are interchangeable, as are ζ and y , and therefore we may interchange them freely in our analysis without any loss in generality.

Before proceeding any further, in order to make this discussion more meaningful, it will be helpful to mention the statistics that are of usual interest to an analyst in a congestion problem such as ours. These were assumed to be

- a) the mean and variance of the waiting time of a customer (μ_w, σ_w^2) ,
- b) the mean and variance of the time that the server remained idle (μ_b, σ_b^2) , and
- c) the mean and variance of the closure time of the system (i.e., the mean and variance of the time required to serve a prespecified number of customers) (μ_c, σ_c^2) .

Now even in a simple system such as ours, because we imposed no restrictions on $F_x(x_0)$ and $G_y(y_0)$ it is not always convenient (and sometimes not possible) to obtain the above mentioned statistics analytically.

For this reason, it is usual that digital simulation be employed in congestion problems for the determination of the above mentioned statistics, even in seemingly simple cases let alone in more complex cases where digital simulation becomes our only solution method. This observation is

encouraging, as it suggests that the conclusions of our analysis will not only be applied to the model of this study, but should also find a wide application because in most congestion problems, digital simulation is usually the only solution method. Following this brief digression we now proceed with our analysis by discussing the way that antithetic variance can be applied in the calculations of μ_w and σ_w^2 .

a) Introduction of the Concept of Antithetic Variance in the Calculations of μ_w and σ_w^2 .

It should be evident from the above discussion that we wish to employ digital simulation in the estimation of the value of μ_w and σ_w^2 , and that our ambition is to introduce the concept of antithetic variance into our methodology in order to minimize the number of observations required for the proper estimation of the above mentioned quantities.

As was suggested earlier, in order to achieve this, we should attempt to obtain two streams of dependent observations w'_i and w''_i ($i = 1, 2, \dots, n$) such that

$$\text{cov}(w', w'') \leq 0 \quad (5.21)$$

$$\text{Now since } w' = f_1(\xi', \zeta') \quad (5.22)$$

$$\text{and } w'' = f_2(\xi'', \zeta'') \quad (5.23)$$

where ξ', ζ', ξ'' and ζ'' are the only parameters which we are able to control, we may postulate that our requirement is that of seeking the relationship between ξ', ζ', ξ'' and ζ'' that will yield such w' and w'' that satisfy equation (5.21).

In order to obtain such a relationship, we need to 123.
 mathematically manipulate equations (5.22) and (5.23), but unfortunately the nature of these equations is such that any mathematical manipulation other than one that is very simple in nature is impossible. This suggests that if we do not wish to abandon the concept of negative correlation because of the above mentioned difficulties, we need to model w , the customer waiting time, in such a way that we can then mathematically manipulate the resulting expressions and obtain the relationship between ξ' , ζ' , ξ'' and ζ'' that will yield negatively correlated w' and w'' .

The mathematical model that we selected for w in this study is given by the following equation:

$$d_j = -(x_j - y_j) \quad j = 1, 2, \dots, 2n \quad (5.24)$$

where d_j is used to characterize the waiting time of the j th customer.

Before proceeding, it is essential that we understand the limitations of our mathematical model (equation 5.24), as this understanding is necessary for the result interpretation presented later in this section.

First we observe that a large (algebraically) d indicates a large waiting time, as desired. This is so because the conditions for a large (algebraically) d are synonymous with those for a queue formation (namely, large y small x). Similarly, we observe that a small (algebraically) d indicates a small waiting time, as desired. This is so because

the conditions for a small (algebraically) d are 124.
synonymous with those for a queue dispersion (namely, large x
small y). From this, we may conclude that d provides an
accurate quantitative description (but not definition) of w
as required.

Second, we observe that d can assume negative values,
while w does not. This suggests that when our system is such
that a queue is not formed, d offers a poor characterization
of w . This is so because the values of d have a definite
bias towards negative values, while w 's values have a bias
towards the zero value. However, when our system is such
that a queue is formed, d offers a good characterization of
 w , because both d and w have a bias towards positive values.
From this, we may conclude that when conditions are such that
a queue is likely to be formed in our system, by negatively
correlating d we achieve (indirectly) a higher degree of
negative correlation in w than when a queue is not likely to
be formed, because d characterizes w better in the former
case than in the latter.

Another point of interest to note is that equation
(5.24) is a subscripted equation in which the waiting time
characterization (d_j) of the j th customer is related to the
interarrival and service time of the j th customer. This sug-
gests that if we are to achieve the maximum negative correla-
tion in d , and hence in w , we must ensure that the customer
interarrival and service times are always related in both

streams of observations (d' and d''). This is usually 125. automatically ensured in a simple system like ours, but there exist exceptions* where that is not true. When these circumstances arise, the user must take precautions to ensure proper alignment of customer interarrivals and customer service times in both streams. The discussion of the effect of misalignment and methods to ensure proper alignment are discussed later, when a more complex system is investigated. Such systems never have automatic alignment and for this reason the discussion is postponed until then where it will be more relevant.

In summary, we have proposed to model equations (5.22) and (5.23) by equation (5.24), i.e.,

$$w' \text{ modeled by } d' = -(x' - y') = -(\phi(\xi') - \psi(\zeta')) \quad (5.25)$$

$$w'' \text{ modeled by } d'' = -(x'' - y'') = -(\phi(\xi'') - \psi(\zeta'')) \quad (5.26)$$

and then we have proposed to find the relationship between ξ' , ζ' , ξ'' and ζ'' so that

$$\text{cov}(d', d'') \leq 0, \quad (5.27)$$

anticipating (to be proved experimentally later) that this will also yield such w' and w'' that equation (5.21) will also be satisfied, because d models the behavior of w , with the limitations enumerated earlier.

*For example, the simulation is achieved by examining the system at discrete (prespecified) time intervals, and the serving strategy is last come, first served.

Now if we assume that we have generated the first stream of observations, d' , from ξ' and ζ' , our problem becomes one of identifying the relationships of ξ'' and ζ'' with ξ' and ζ' , i.e.,

$$\xi'' = \xi(\xi', \zeta') \quad (5.28)$$

$$\text{and } \zeta'' = \zeta(\xi', \zeta') \quad (5.29)$$

so that when ξ'' and ζ'' are used to generate d'' , equation (5.27) is satisfied. (Remember that as with equations (5.19) and (5.20), ξ'' and ζ'' must be independent.)

Before proceeding with the determination of equations (5.28) and (5.29), the following basic characteristic of digital simulation should be borne in mind. It is readily observable that in digital simulation many random numbers need to be generated in order to obtain our solution. Bearing in mind that as each equation that involves random numbers must be evaluated each time a new random number is generated, and since both equations (5.28) and (5.29) involve random numbers, it is most advantageous (from the economic point of view) for us to adopt the simplest form of these equations that will satisfy our needs. For this reason, it is proposed that we consider only the simplest forms of equations (5.28) and (5.29), namely,

$$\xi'' = \xi(\xi') \quad (5.30)$$

$$\zeta'' = \zeta(\zeta') \quad (5.31)$$

$$\text{and } \xi'' = \xi(\zeta') \quad (5.30a)$$

$$\zeta'' = \zeta(\xi') \quad (5.31a)$$

as this should minimize the execution time of our algorithm.

Now we proceed with the determination of the functional relationships of equations (5.30), (5.31) and (5.30a), (5.31a).

(1) Here, we investigate the situation where

$$\xi'' = \xi(\xi') \quad (5.30)$$

$$\text{and } \zeta'' = \zeta(\zeta') \quad (5.31)$$

By equation (5.25)

$$\begin{aligned} \mu_{d'} &= E(d') = -(E(x') - E(y')) \\ &= -(\mu_i - \mu_s) \end{aligned}$$

where $\mu_{d'}$ is the mean or expected value of d'

$$\mu_i = E(x')$$

the mean customer interarrival time

$$\text{and } \mu_s = E(y')$$

the mean customer service time.

Similarly by equation (5.26),

$$\begin{aligned} \mu_{d''} &= E(d'') = -(E(x'') - E(y'')) \\ &= -(\mu_i - \mu_s) \end{aligned}$$

where $\mu_{d''}$ is the mean or expected value of d''

$$\mu_i = E(x'')$$

because both x' and x'' pertain to the same process

$$\text{and } \mu_s = E(y'')$$

because both y' and y'' pertain to the same process.

Therefore it follows that

$$\mu_{d'} = \mu_{d''} = -(\mu_i - \mu_s) \quad (5.32)$$

$$\begin{aligned}
\sigma_{d'}^2 &= E\{[d' - E(d')]^2\} \\
&= E\{[-(x' - y') + (\mu_i - \mu_s)]^2\} \\
&= E\{[-(x' - \mu_i) + (y' - \mu_s)]^2\} \\
&= \sigma_i^2 + \sigma_s^2 - 2E\{(x' - \mu_i)(y' - \mu_s)\}
\end{aligned}$$

where $\sigma_{d'}^2$ is the variance of variable d'

$$\sigma_i^2 = E\{(x' - \mu_i)^2\}$$

the variance of the customer interarrival time.

$$\sigma_s^2 = E\{(y' - \mu_s)^2\}$$

the variance of the customer service time.

Now because x' and y' are independent it follows that

$$\sigma_{d'}^2 = \sigma_i^2 + \sigma_s^2$$

because $E(x'y') = E(x') E(y')$

Similarly from equations (5.26) and (5.32)

$$\begin{aligned}
\sigma_{d''}^2 &= E\{[d'' - E(d'')]^2\} \\
&= E\{[-(x'' - y'') + (\mu_i - \mu_s)]^2\} \\
&= E\{[-(x'' - \mu_i) + (y'' - \mu_s)]^2\} \\
&= \sigma_i^2 + \sigma_s^2 - 2E\{(x'' - \mu_i)(y'' - \mu_s)\}
\end{aligned}$$

where $\sigma_{d''}^2$ is the variance of variable d''

$$\sigma_i^2 = E\{(x'' - \mu_i)^2\}$$

because both x' and x'' pertain to the same process

$$\sigma_s^2 = E\{(y'' - \mu_s)^2\}$$

because both y' and y'' pertain to the same process

Now because x'' and y'' are independent it follows that

$$\sigma_{d''}^2 = \sigma_i^2 + \sigma_s^2$$

because $E(x''y'') = E(x'') E(y'')$

Therefore it follows that

129.

$$\sigma_{d'}^2 = \sigma_{d''}^2 = \sigma_i^2 + \sigma_s^2 \quad (5.33)$$

By equations (5.25) and (5.26)

$$\begin{aligned} \text{cov}(d', d'') &= E\{[d' - E(d')][d'' - E(d'')]\} \\ &= E\{d'd'' + E(d')E(d'') - d'E(d'') - d''E(d')\} \\ &= E[d'd''] - E(d')E(d'') \\ &= E\{(x' - y')(x'' - y'')\} - E\{-(x' - y')\}E\{-(x'' - y'')\} \\ &= E\{x'x'' + y'y'' - x'y'' - x''y'\} - \\ &\quad - \{E(x') - E(y')\}\{E(x'') - E(y'')\} \end{aligned}$$

Now because x' is independent of y' and y'' , and

y' is independent of x' and x'' , it follows that

$$E(x'y') = E(x')E(y')$$

$$E(x'y'') = E(x')E(y'')$$

$$\text{and } E(x''y') = E(x'')E(y')$$

therefore the above equation becomes

$$\text{cov}(d', d'') = E(x'x'') + E(y'y'') - \mu_i^2 - \mu_s^2 \quad (5.34)$$

By equations (5.19) and (5.20) the above equation becomes

$$\text{cov}(d', d'') = E[\phi(\xi')\phi(\xi'')] + E[\psi(\zeta')\psi(\zeta'')] - \mu_i^2 - \mu_s^2 \quad (5.35)$$

Our requirement for maximum efficiency (see equation 5.18)

can be expressed mathematically as follows:

$$\text{Min } \{\text{cov}(d', d'')\} \quad (5.36)$$

Now from equation (5.35), because μ_i^2 and μ_s^2 are positive quantities, the requirement of equation (5.36) is equivalent to

$$\text{Min } \{E[\phi(\xi')\phi(\xi'')] + E[\psi(\zeta')\psi(\zeta'')]\} \quad (5.37)$$

Now because ξ' , ζ' , ξ'' and ζ'' are random variables drawn 130.
 from a $U(0,1)$ distribution and

$$\xi'' = \xi(\xi')$$

$$\zeta'' = \zeta(\zeta')$$

(see equations 5.30 and 5.31)

it follows that equation (5.37) can be rewritten as follows:

$$\text{Min} \left\{ \int_0^1 \phi(\xi') \phi(\xi'') d\xi' + \int_0^1 \psi(\zeta') \psi(\zeta'') d\zeta' \right\} \quad (5.38)$$

Now because $x' = \phi(\xi')$ (see equation 5.19)

then $\phi(\xi')$ is monotonic

then the integral

$$\int_0^1 \phi(\xi') \phi(\xi'') d\xi'$$

is minimum when $\phi(\xi'')$ is monotonic in the opposite sense
 of $\phi(\xi')$ * (5.40)

Similarly, because $y' = \psi(\zeta')$ (see equation 5.20)

then $\psi(\zeta')$ is monotonic

then the integral

$$\int_0^1 \psi(\zeta') \psi(\zeta'') d\zeta'$$

is minimum when $\psi(\zeta'')$ is monotonic in the opposite sense of
 $\psi(\zeta')$ * (5.41)

In other words, the requirement of equation (5.36) is
 equivalent to the requirements set out by equations (5.40)

* For proof see Theorem 378, Hardy et al, Inequalities (for
 complete title refer to the bibliography).

and (5.41)*. Remembering that for the reasons given earlier in this section, it is to our advantage to have the simplest possible relationships in expressions involving random numbers, the following simple functional relationships for equations (5.30) and (5.31) satisfying the requirements set out by equations (5.40) and (5.41) are proposed.

$$\xi'' = 1 - \xi' \quad (5.42)$$

$$\text{and } \zeta'' = 1 - \zeta' \quad (5.43)$$

Please note that because ξ' and ζ' are both drawn from $U(0,1)$ distributions, then ξ'' and ζ'' also have $U(0,1)$ p.d.f.'s as required**, and as ξ' and ζ' are independent, then ξ'' and ζ'' are also independent as required.

For the proof that our transformation (see equations (5.42) and (5.43)) satisfies equation (5.27), the reader is referred to Appendix A, part 3.

Summarizing, if we generate a stream of n observations (w') using random variables ξ' and ζ' , and then generate a dependent stream of n observations (w'') using random variables ξ'' and ζ'' generated by equations (5.42) and (5.43), it is anticipated that equation (5.21) is satisfied (to be verified experimentally). If this is the case, then μ_w and σ_w^2 can be computed by equations (5.2) and (5.11) respectively, and the anticipated gain (i.e. $\eta > 1$) in our methodology has been achieved.

*Please note that this statement is true because the minimum value of the sum of two independent quantities is the same as the sum of the minimum values of these two quantities.

**Easily verified using equations A-1 and A-2 of Appendix A.

(2) Here, we investigate the situation where 132.

$$\xi'' = \xi(\zeta') \quad (5.30)$$

$$\zeta'' = \zeta(\xi') \quad (5.31)$$

As in Case 1

$$\mu_{d'} = \mu_{d''} = -(\mu_i - \mu_s) \quad (5.32)$$

$$\sigma_{d'}^2 = \sigma_{d''}^2 = \sigma_i^2 + \sigma_s^2 \quad (5.33)$$

and
$$\text{cov}(d', d'') = E\{x'x'' + y'y'' - x'y'' - x''y'\} - \{E(x') - E(y')\} \{E(x'') - E(y'')\}$$

Now because x' is independent of y' and x'' and

y' is independent of y'' and x' then

$$E(x'y') = E(x') E(y')$$

$$E(x'x'') = E(x') E(x'')$$

and
$$E(y'y'') = E(y') E(y'')$$

then the above equation for $\text{cov}(d', d'')$ becomes

$$\text{cov}(d', d'') = 2\mu_i\mu_s - E(x'y'') - E(x''y') \quad (5.44)$$

By equations (5.19) and (5.20), equation (5.44) becomes

$$\text{cov}(d', d'') = 2\mu_i\mu_s - E\{\phi(\xi')\psi(\zeta'')\} - E\{\phi(\xi'')\psi(\zeta')\} \quad (5.45)$$

Now from equation (5.45), because μ_i and μ_s are non-negative quantities the requirement of equation (5.46) is equivalent to

$$\text{Max} \{E\{\phi(\xi')\psi(\zeta'')\} + E\{\phi(\xi'')\psi(\zeta')\}\} \quad (5.46)$$

Now because ξ' , ζ' , ξ'' and ζ'' are random variables drawn from a $U(0,1)$ distribution and

$$\xi'' = \xi(\zeta')$$

$$\zeta'' = \zeta(\xi')$$

(see equations 5.30a and 5.31a)

it follows that equation (5.46) may be rewritten as follows:^{133.}

$$\text{Max} \left\{ \int_0^1 \phi(\xi') \psi(\zeta'') d\xi' + \int_0^1 \phi(\xi'') \psi(\zeta') d\zeta' \right\} \quad (5.47)$$

Now because $x' = \phi(\xi')$ (see equation 5.19)

then $\phi(\xi')$ is monotonic

then the integral

$$\int_0^1 \phi(\xi') \psi(\zeta'') d\xi'$$

is maximum when $\psi(\zeta'')$ is monotonic in the same sense as

$$\phi(\xi')^* \quad (5.48)$$

Similarly, because $y' = \psi(\zeta')$ (see equation 5.20)

then $\psi(\zeta')$ is monotonic

then the integral

$$\int_0^1 \phi(\xi'') \psi(\zeta') d\zeta'$$

is maximum when $\phi(\xi'')$ is monotonic in the same sense as

$$\psi(\zeta')^* \quad (5.49)$$

In other words, the requirement of equation (5.36) is equivalent to the requirement set out by equations (5.48) and (5.49)**. Remembering that for the reasons given earlier in

*For proof see Theorem 378, Hardy et al, Inequalities (for complete title refer to the bibliography).

**Please note that this statement is true because the maximum value of the sum of two independent quantities is the same as the sum of the maximum values of these two quantities.

this section, it is to our advantage to have the simplest possible relationships in expressions involving random numbers, the following simple functional relationships for equations (5.30a) and (5.31a) satisfying the requirements set out by (5.48) and (5.49) are proposed.

$$\xi'' = \zeta' \quad (5.50)$$

$$\zeta'' = \xi' \quad (5.51)$$

Please note that because ξ' and ζ' are both drawn from $U(0,1)$ distributions, then ξ'' and ζ'' also have $U(0,1)$ p.d.f.'s as required, and as ξ' and ζ' are independent then ξ'' and ζ'' are also independent as required.

For the proof that our transformation (see equations 5.50 and 5.51) satisfies equation (5.25), the reader is referred to Appendix A, part 4.

(3) Here, we provide the experimental proof that by negatively correlating d' and d'' , using the previously derived transformations, we also achieve a certain degree of negative correlation between w' and w'' . Because of budgetary limitation, our experiments utilized only the transformations given by equations (5.42) and (5.43). The results that would have been obtained if the transformations given by equations (5.50) and (5.51) had been used would be expected to lead to the same conclusions, as both transformations are equivalent. It is therefore anticipated that no loss in the generality of our conclusions would be incurred by our self-imposed limitation.

System:

One Queue One Server

Rules of Operation

- i) Initialize the system at the beginning of each sample run by emptying the Queue and the Server.
- ii) The service strategy is first come, first served.
- iii) Once a customer joins the queue during a sample run he cannot leave it.
- iv) The customer interarrival time is generated from a $U(a_i, b_i)$ distribution, and the customer service time is generated from a $U(a_s, b_s)$ distribution.
- v) The customer interarrival and service times are independent of each other.

Experimental Details

- i) Each sample is to involve 200 observations, i.e., in each sample 200 customers are to be served.
- ii) Each experimental value is to be computed from the results of 50 samples.
- iii) The starting value of the seeds for the first sample in each case (a sequence of 50 samples) is 65539 for the customer interarrival time, and 65533 for the customer service time.

iv) In each case, a_i , b_i , a_s and b_s are so arranged (see 136. Appendix A, part 5) that

$$\sigma_i^2 = \sigma_s^{2*}$$

$$\mu_s = \rho \mu_i \quad (\rho \text{ is the traffic intensity, so } \rho \leq 1)$$

$$\mu_i = 4.5$$

The results obtained from our analysis are shown graphically in Figs. 5-1 and 5-2, where η is plotted against σ_i^2 (and σ_s^2) and ρ . Because in these graphs η is never less than 1, which is the condition for $\text{cov}(w', w'')$ to be non positive***, we have experimentally shown that by negatively correlating d' and d'' using the transformations given by equations (5.42) and (5.43), we have indeed achieved a certain degree of negative correlation between w' and w'' also, as we set out to prove.

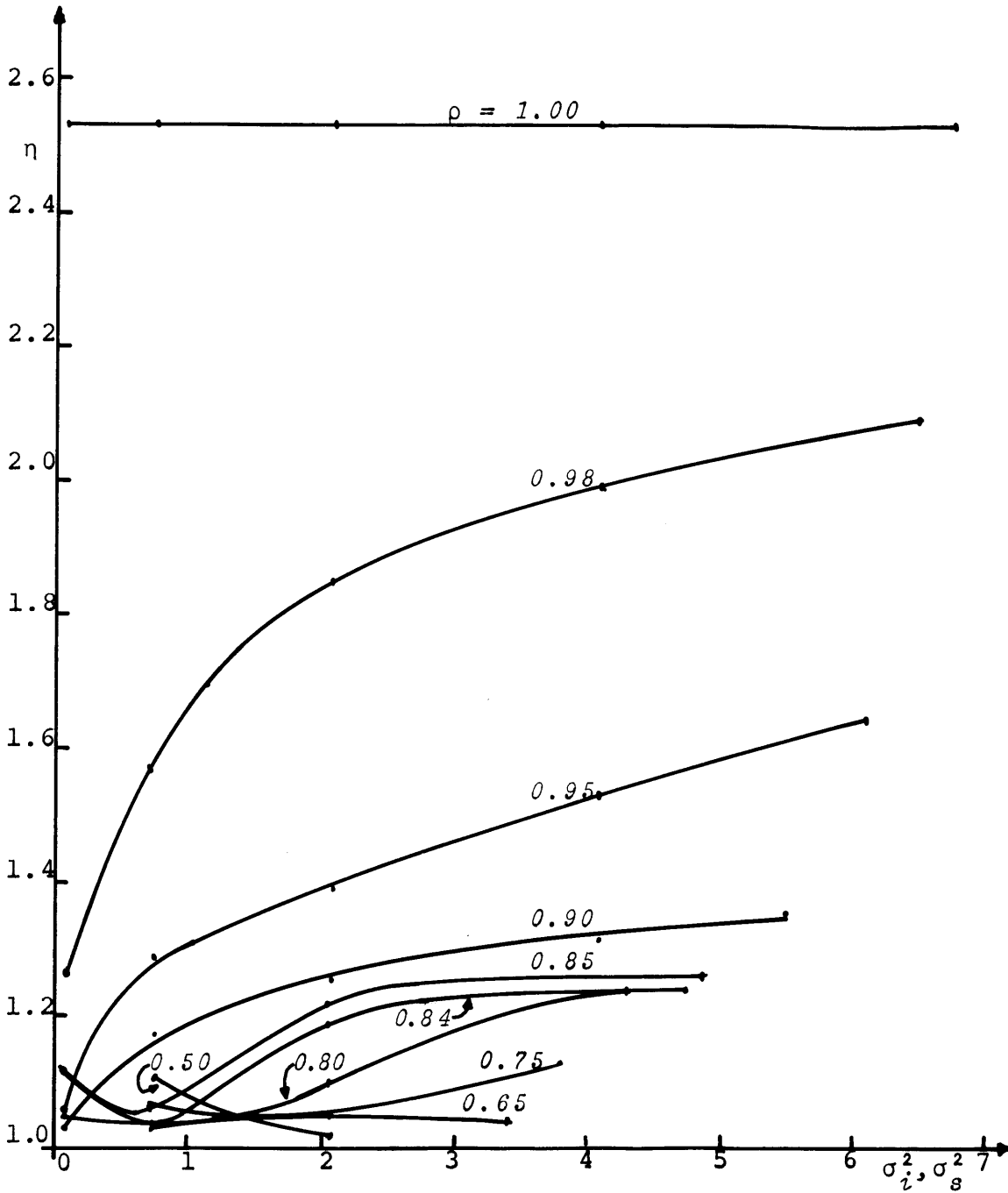
Before leaving the subject under discussion, it would be advantageous to analyze the results shown in Figs. 5-1 and 5-2 and to draw any conclusions that we may. Such an analysis is useful because we may then extrapolate our findings with confidence in more general cases.

From Fig. 5-1, we may deduce that for a given ρ , as σ_i^2 (and σ_s^2) increases, so does the efficiency of our methodology.

*The values of σ_i^2 (and σ_s^2) investigated in this study are marked in Fig. 5-1.

**The values of ρ investigated in this study are shown in Fig. 5-1.

***See the discussion associated with equations (5.10) and (5.11).



1Q-1S System Mean Customer Waiting Time
 (η vs σ_i^2 and σ_s^2)

Fig. 5-1

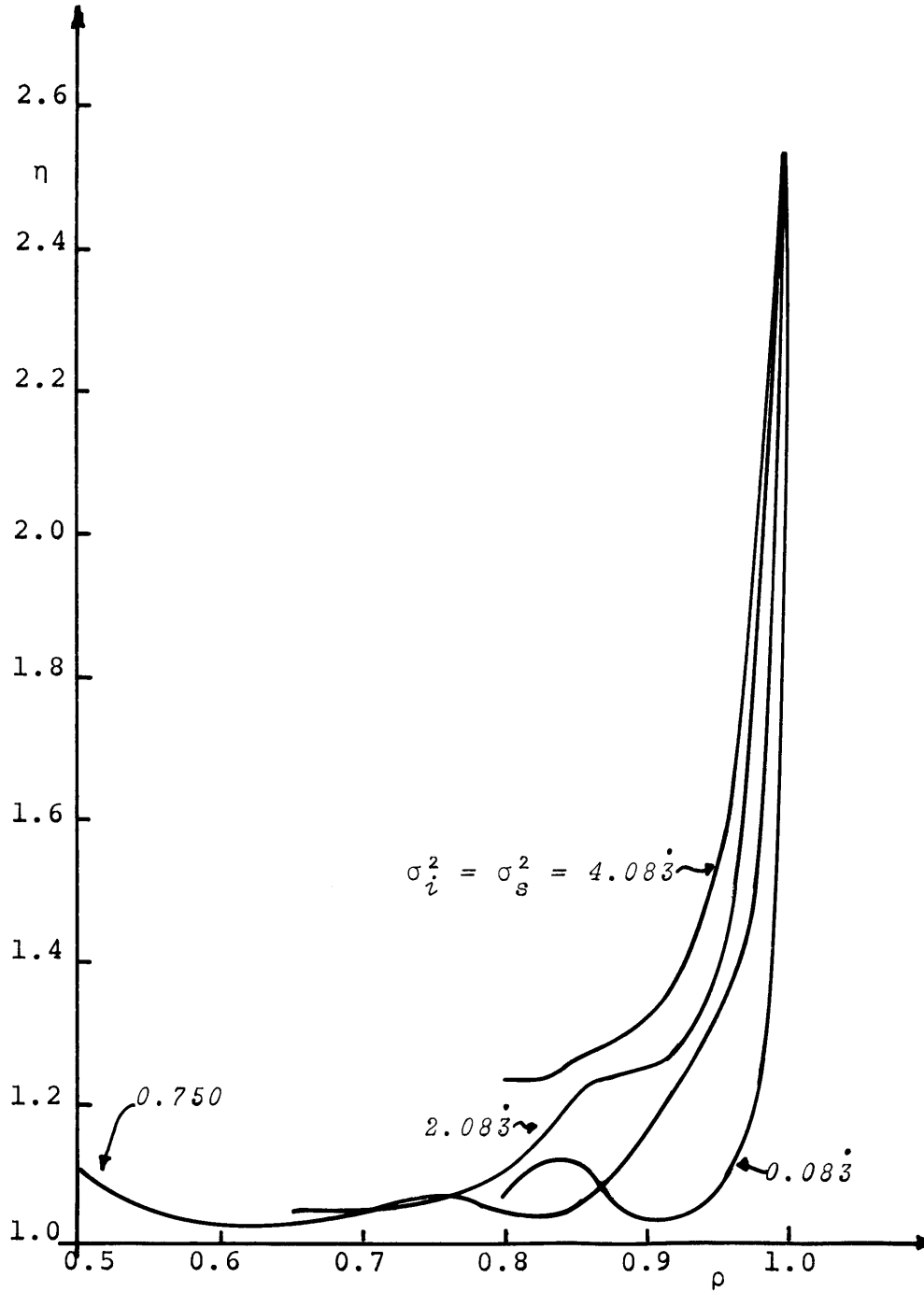
IQ-1S System Mean Customer Waiting Time (η vs ρ)

Fig. 5-2

This is in accordance with our observations made in our earlier discussion of equation (5.24), because an increase in the value of σ_i^2 (and σ_s^2) causes a queue to form, and hence it is expected that d will offer a better characterization of w than when the queue disperses at low σ_i^2 (and σ_s^2).

From Fig. 5-2, we may deduce that for a given σ_i^2 (and σ_s^2), as ρ increases, so does the efficiency of our methodology. This again is in accordance with our observations made when discussing equation (5.24), because an increase in the value of ρ causes a queue to form, and hence it is expected that d will offer a better characterization of w than when the queue disperses at low ρ .

The irregularities present in both Figs. 5-1 and 5-2 can be explained by the fact that η itself is a random variable. To substantiate this argument, and in order to verify that the conclusions drawn from Figs. 5-1 and 5-2 are correct, an additional experiment was performed where ρ was kept constant at the value of 0.90, and 8 additional values of η were obtained (see Appendix A, part 6 for particulars of this experiment). The results of this experiment are shown in Fig. 5-3, where we can observe with more confidence that for a given ρ ($\rho = .90$), as σ_i^2 (and σ_s^2) increases so does the efficiency of our methodology. This is so because an increase in the value of σ_i^2 (and σ_s^2) causes a queue to form (shown in Fig. 5-4 by plotting the mean of the mean customer waiting time of our latter experiment), and hence it is expected that d will

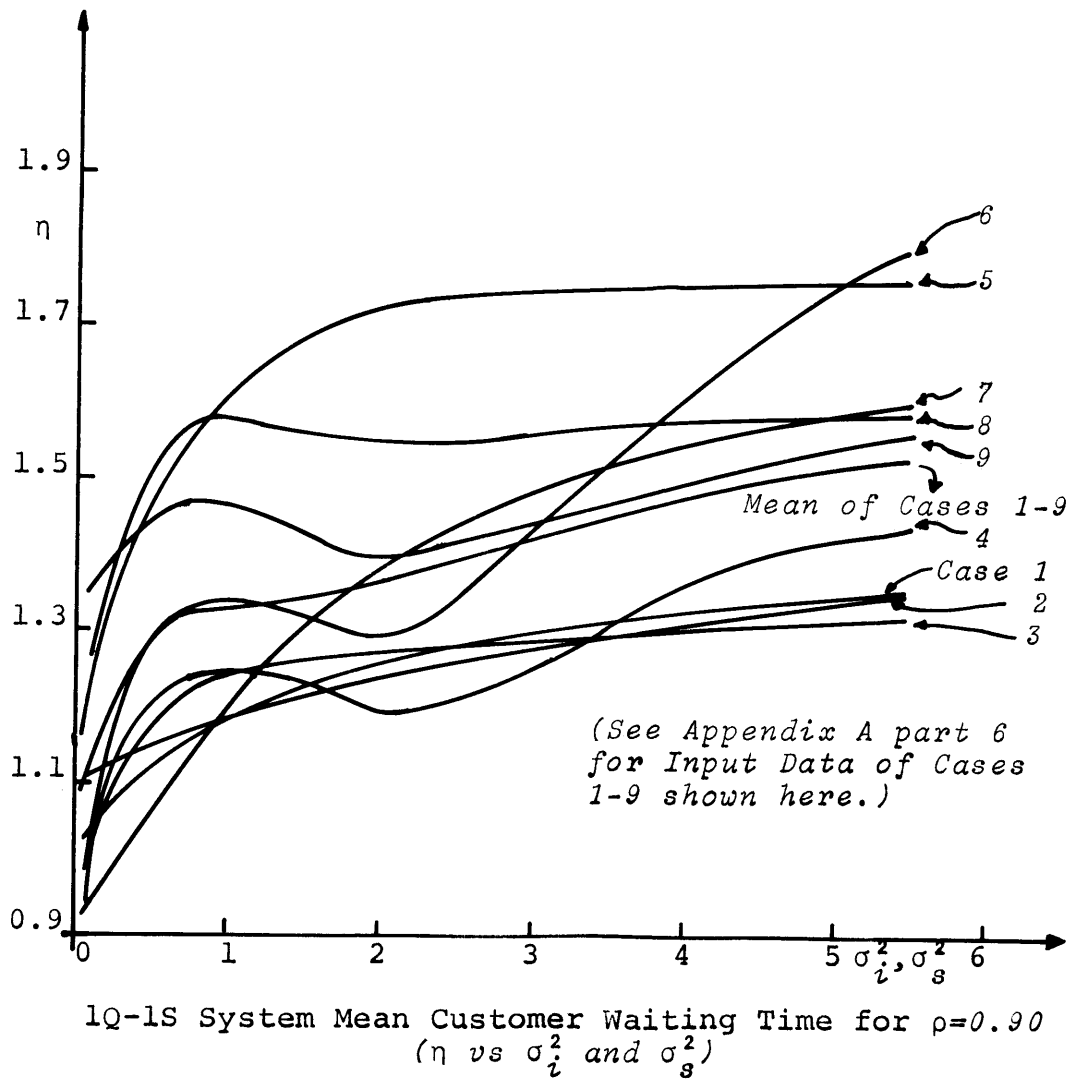


Fig. 5-3

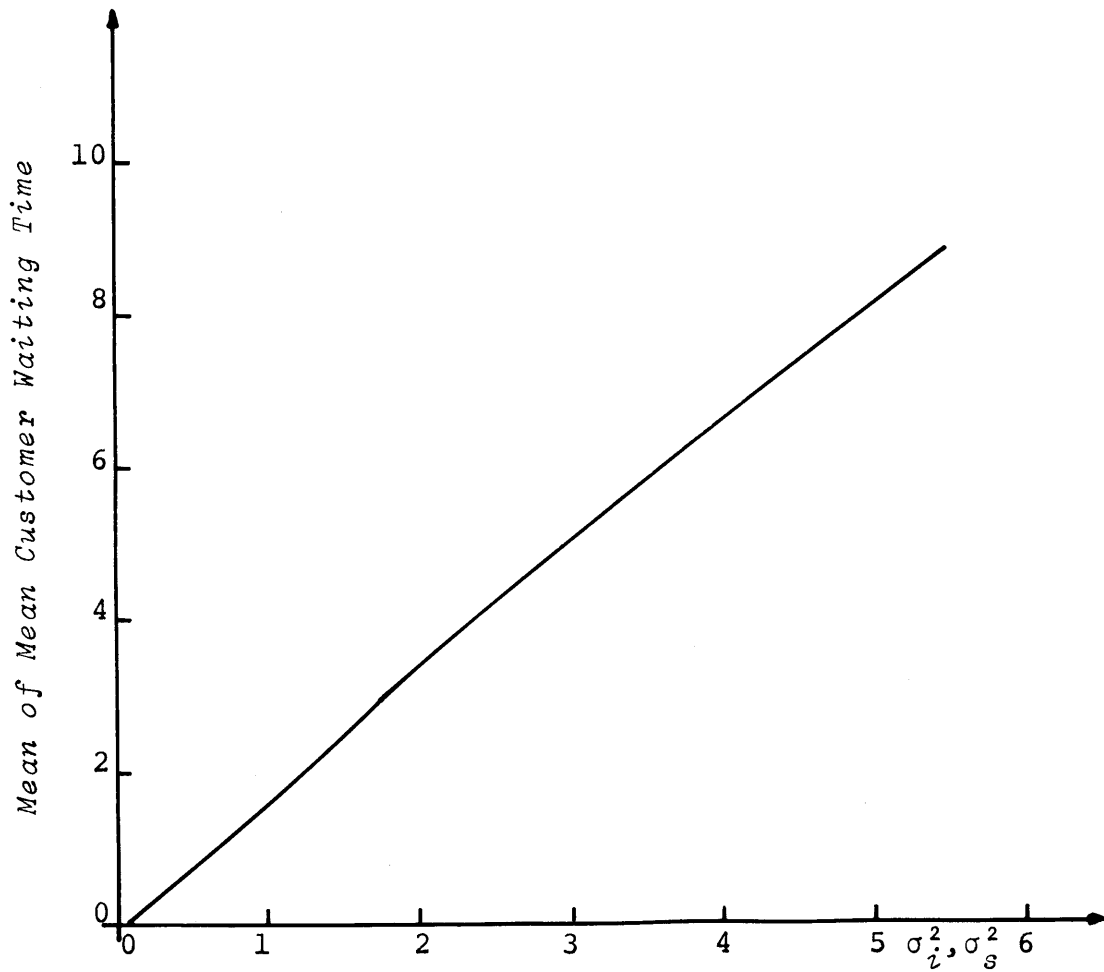


Fig. 5-4. 1Q-1S System.
Mean of Mean Customer Waiting Time vs
Variance.

offer a better characterization of w (as was observed in 142. the discussion of equation (5.24)), than when the queue disperses at low σ_i^2 and σ_s^2).

Next, arguing logically, we may deduce that as ρ or σ_i^2 (and σ_s^2) increases, then the likelihood of a queue formation increases, regardless of the distributions used to model the customer interarrival and service times. Then because the above conclusions are based only on the presence or absence of a queue in our system*, we may extrapolate our findings from the above and conclude that, in general, as the likelihood of queue formation in our system increases, so too does the efficiency of our methodology.

In the author's opinion, it is advisable for the user to employ the suggested technique for negatively correlating w' and w'' even in cases where the efficiency is expected to be very low, because the transformations involved are simple and non time consuming, and the experimental results have always yielded efficiencies greater than 1.

The above completes our discussion on the introduction of antithetic variance in the calculation of μ_w and σ_w^2 . Now, we proceed with our analysis by discussing the way that antithetic variance may be applied in the calculations of μ_b and σ_b^2 .

*Remember that transformations given by equations (5.42), (5.43), (5.50) and (5.51) were derived for arbitrary $F_x(x_o)$ and $G_y(y_o)$ (see the discussion of equations 5.19 and 5.20).

(b) Introduction of the Concept of Antithetic Variance into the Calculations of μ_b and σ_b^2 . (Server Idle)

As in the case dealing with customer waiting time, we are also attempting here to obtain two streams of dependent observations b'_i (the time that the server remained idle) and b''_i ($i=1,2,\dots,n$) such that

$$\text{cov}(b', b'') \leq 0 \quad (5.52)$$

Now because $b' = f_1(\xi', \zeta')$ (5.53)

and $b'' = f_2(\xi'', \zeta'')$ (5.54)

where ξ' , ζ' , ξ'' and ζ'' are the only parameters we are able to control, we may postulate that our requirement is that of seeking the relationship between ξ' , ζ' , ξ'' and ζ'' that will yield such b' and b'' that satisfy equation (5.52). Unfortunately, as in the case of equations (5.22) and (5.23), equations (5.53) and (5.54) allow no mathematical manipulation other than one that is very simple in nature. For this reason, in order to continue, we must mathematically model b in such a manner that mathematical manipulation is possible on the resulting equations, thus obtaining the required relationship between ξ' , ζ' , ξ'' and ζ'' that will yield negatively correlated b' and b'' .

The mathematical model that we selected for b in this study is given by the following equation:

$$d_j = (x_j - y_j) \quad j=1,2,\dots,2n \quad (5.55)$$

where d is used to characterize the time that the server remained idle.

Before proceeding, it is essential that we understand the limitations of our mathematical model (equation 5.55), as this understanding is necessary for the result interpretation presented later in this section.

First, we observe that an algebraically large d indicates that the server remained idle a long time, as desired. This is so because the conditions for an algebraically large d are synonymous with those for a queue dispersion (namely, large x , small y). Similarly, we observe that an algebraically small d indicates that the server remained idle little or no time at all, as desired. This is so because the conditions for an algebraically small d are synonymous with those for a queue formation (namely, small x , large y). From this, we may conclude that d (see equation 5.55) provides an accurate quantitative description (but not definition) of b , as required.

Second, we observe that d (see equation 5.55) may assume negative values, while b does not. This suggests that when our system is such that a queue is not formed, d offers a good characterization of b , because both d and b have a bias towards positive values. However, when our system is such that a queue is formed, d offers a poor characterization of b . This is so because the values of d have a definite bias towards negative values, while b 's values have a bias towards the zero value. From this, we may conclude that when conditions are such that a queue is not likely to be formed in our system, by negatively correlating d we achieve (indirectly)

a higher degree of negative correlation in b than when a queue is likely to be formed, because d characterizes b better in the former case than in the latter.

It is of interest to note that the mathematical model for w characterizes the customer waiting time best when there is a queue in our system, while the mathematical model for b characterizes best the time that the server remains idle when there is a tendency for a queue dispersion in our system.

Finally, because equation (5.55) is a subscripted equation, and of the same nature as equation (5.24), the misalignment comments made concerning equation (5.24) apply here too.

In summary, we have proposed to model equations (5.53) and (5.54) by (5.55), i.e.,

$$b' \text{ modeled by } d' = (x' - y') = (\phi(\xi') - \psi(\zeta')) \quad (5.56)$$

$$b'' \text{ modeled by } d'' = (x'' - y'') = (\phi(\xi'') - \psi(\zeta'')) \quad (5.57)$$

and then we have proposed to find the relationship between ξ' , ζ' , ξ'' and ζ'' so that

$$\text{cov}(d', d'') \leq 0 \quad (5.27)$$

anticipating (to be proved experimentally later) that this will also yield such b' and b'' that equation (5.52) will also be satisfied, because d models the behavior of b , with the limitations enumerated earlier.

Now if we continue along the same lines as we did in the case of customer waiting time, our task becomes that of finding the functional relationships between ξ' , ζ' , ξ'' and ζ'' in equations (5.30) and (5.31) and (5.30a) and (5.31a).

1. Here we investigate the situation where

$$\xi'' = \xi(\xi') \quad (5.30)$$

$$\text{and } \zeta'' = \zeta(\zeta') \quad (5.31)$$

By equation (5.56)

$$\begin{aligned} \mu_{d'} &= E(d') = E(x') - E(y') \\ &= \mu_i - \mu_s \end{aligned}$$

Similarly by equation (5.57)

$$\begin{aligned} \mu_{d''} &= E(d'') = E(x'') - E(y'') \\ &= \mu_i - \mu_s \end{aligned}$$

Therefore it follows that

$$\mu_{d'} = \mu_{d''} = \mu_i - \mu_s \quad (5.58)$$

By equations (5.56) and (5.58)

$$\begin{aligned} \sigma_{d'}^2 &= E\{[d' - E(d')]^2\} \\ &= E\{[(x' - y') - (\mu_i - \mu_s)]^2\} \\ &= \sigma_i^2 + \sigma_s^2 - 2E\{(x' - \mu_i)(y' - \mu_s)\} \\ &= \sigma_i^2 + \sigma_s^2 \end{aligned}$$

$$\text{because } E(x'y') = E(x') E(y')$$

Similarly by equations (5.57) and (5.58)

$$\begin{aligned} \sigma_{d''}^2 &= E\{[d'' - E(d'')]^2\} \\ &= E\{[(x'' - y'') - (\mu_i - \mu_s)]^2\} \\ &= \sigma_i^2 + \sigma_s^2 - 2E\{(x'' - \mu_i)(y'' - \mu_s)\} \\ &= \sigma_i^2 + \sigma_s^2 \end{aligned}$$

$$\text{because } E(x''y'') = E(x'') E(y'')$$

Therefore it follows that

147.

$$\sigma_{d'} = \sigma_{d''} = \sigma_i^2 + \sigma_s^2 \quad (5.33)$$

By equations (5.56) and (5.57)

$$\begin{aligned} cov(d', d'') &= E\{[d' - E(d')][d'' - E(d'')]\} \\ &= E[d'd''] - E(d') E(d'') \\ &= E\{(x' - y')(x'' - y'')\} - E(x' - y') E(x'' - y'') \\ &= E\{x'x'' + y'y'' - x'y'' - x''y'\} - \\ &\quad - \{E(x') - E(y')\} \{E(x'') - E(y'')\} \end{aligned}$$

which is identical to the equation obtained when we were discussing w .

It therefore follows that

$$cov(d', d'') = E\{\phi(\xi')\phi(\xi'')\} + E\{\psi(\zeta')\psi(\zeta'')\} - \mu_i^2 - \mu_s^2 \quad (5.35)$$

and as the remaining discussion on the derivation of the required functional relationships is based upon equation (5.35) the results may be obtained directly from our earlier analysis and are given below for easy reference as equations (5.42) and (5.43).

$$\text{i.e.} \quad \xi'' = 1 - \xi' \quad (5.42)$$

$$\text{and} \quad \zeta'' = 1 - \zeta' \quad (5.43)$$

2. Here, we investigate the situation where

$$\xi'' = \xi(\zeta') \quad (5.30a)$$

$$\zeta'' = \zeta(\xi') \quad (5.31a)$$

As in the case described immediately above

$$\mu_{d'} = \mu_{d''} = \mu_i - \mu_s \quad (5.58)$$

$$\sigma_{d'}^2 = \sigma_{d''}^2 = \sigma_i^2 + \sigma_s^2 \quad (5.33)$$

and

$$cov(d', d'') = E\{x'x'' + y'y'' - x'y'' - x''y'\} - \{E(x') - E(y')\} \{E(x'') - E(y'')\}$$

which is identical to the equation obtained when we were discussing w .

It therefore follows that

$$\text{cov}(d', d'') = 2\mu_z \mu_g - E\{\phi(\xi')\psi(\zeta'')\} - E\{\phi(\xi'')\psi(\zeta')\} \quad (5.45)$$

and as the remaining discussion is based upon equation (5.45) we may immediately state the required functional relationships, using the results from our earlier analysis, as

$$\xi'' = \zeta' \quad (5.50)$$

$$\text{and} \quad \zeta'' = \xi' \quad (5.51)$$

3. Here, we provide the experimental proof that by negatively correlating d' and d'' (see equations 5.56 and 5.57), using the previously derived transformations, we also achieve a certain degree of negative correlation between b' and b'' . Again, because of budgetary limitations, our experiments utilized only the transformations given by equations (5.42) and (5.43). The results that would have been obtained if the transformations given by equations (5.50) and (5.51) had been used would be expected to lead to the same conclusions, as both transformations are equivalent. It is therefore again anticipated that no loss in the generality of our conclusions would be incurred by our self imposed limitation.

Experiment Definition

The experiment used is identical to that performed in the case of w .

The results obtained from our analysis are shown graphically in Fig. 5-5, where η is plotted against σ_z^2 (and σ_s^2)* for different values of ρ ** . Because in these graphs η is never less than 1, which is the condition for $cov(b', b'')$ *** to be non-positive, we have experimentally shown that by negatively correlating d' and d'' using the transformations given by equations (5.42) and (5.43), we have indeed achieved a certain degree of negative correlation between b' and b'' also, as we set out to prove.

Before leaving the subject under discussion, it would be advantageous to analyze the results shown in Fig. 5-5 and to draw any conclusions that we may. Such an analysis is useful because we may then extrapolate our findings with confidence in more general cases.

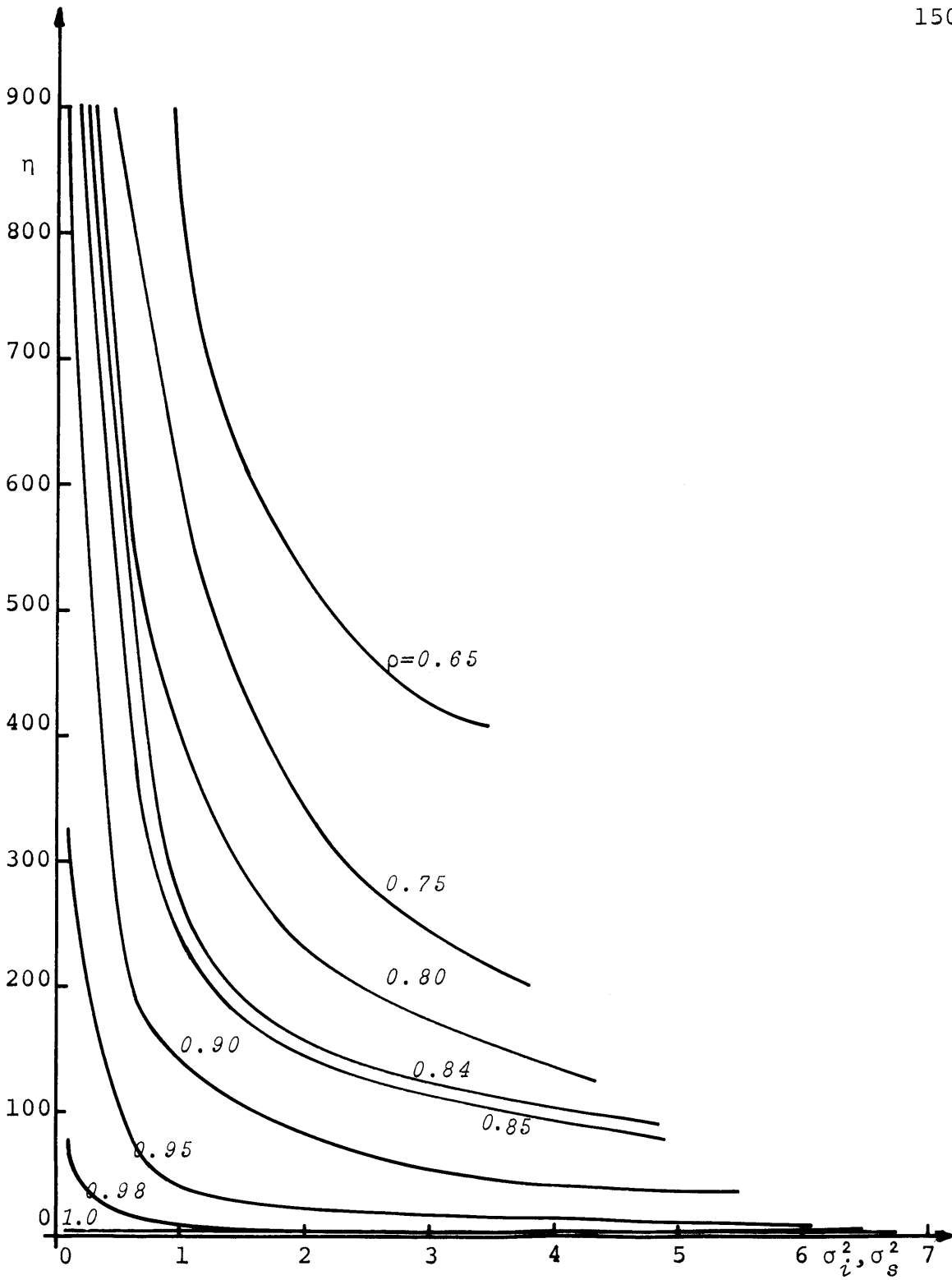
From Fig. 5-5 we may deduce

i) For a given ρ , as σ_z^2 (and σ_s^2) increases the efficiency of our methodology decreases. This is in accordance with our observations made in our earlier discussion of equation (5.55), because an increase in the value of σ_z^2 (and σ_s^2) causes a queue to form, and hence it is expected that d will offer a poorer characterization of b than when the queue disperses at low σ_z^2 (and σ_s^2).

*The values of σ_z^2 (and σ_s^2) investigated in this study are marked in Fig. 5-1.

**The values of ρ investigated in this study are shown in Fig. 5-1.

***See the discussion associated with equations (5.10) and (5.11).



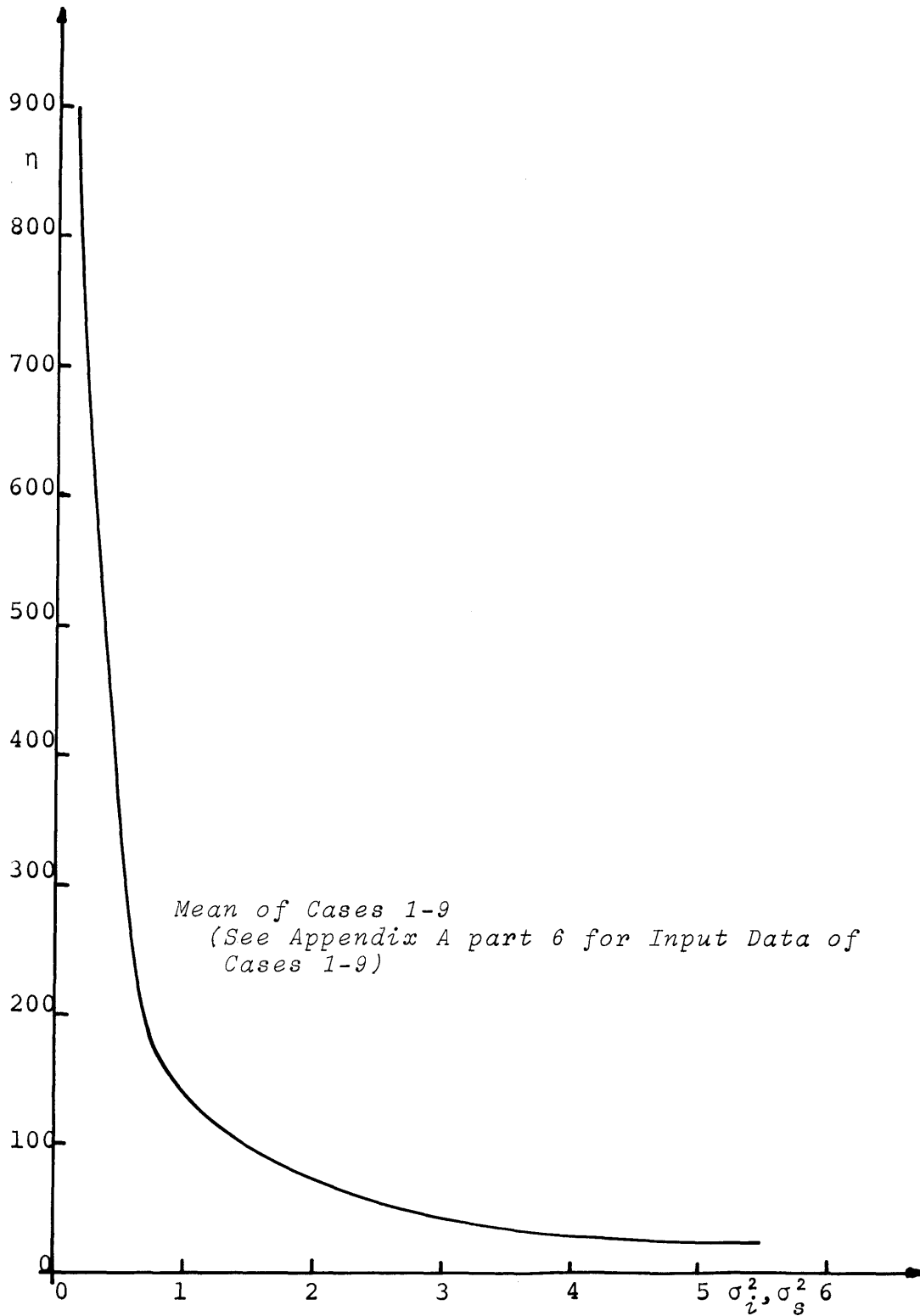
1Q-1S System Mean Time that the Server Remained Idle
 (η vs σ_i^2 and σ_s^2)

Fig. 5-5

ii) For a given σ_l^2 (and σ_s^2), as ρ increases the 151. efficiency of our methodology decreases. This again is in accordance with our observations made when discussing equation (5.55), because an increase in the value of ρ causes a queue to form and hence it is expected that d will offer a poorer characterization of b than when the queue disperses at low ρ .

As was observed when discussing Figs. 5-1 and 5-2, η is a random variable and so in order to verify that the conclusions drawn from Fig. 5-5 are correct, the same experiment performed in the case of w was repeated here too. The results of this experiment are shown in Fig. 5-6, where we may observe with more confidence that for a given ρ ($\rho = .90$), as σ_l^2 (and σ_s^2) increases the efficiency of our methodology decreases. This is so because an increase in the value of σ_l^2 (and σ_s^2) causes a queue to form (shown in Fig. 5-4 by plotting the mean of the mean customer waiting time of our latter experiment), and hence it is expected that d will offer a poorer characterization of b , (as was observed in the discussion of equation 5.55), than when the queue disperses at low σ_l^2 (and σ_s^2).

As was already observed when discussion equations (5.24) and (5.55), namely, that d offers a better characterization for w when there is a queue in our system, while the characterization for b is best when there is no queue, then the efficiency of our methodology as a function of the likelihood



1Q-1S System Mean Time that Server Remained Idle for $\rho=0.90$
(η vs σ_i^2 and σ_s^2)

Fig. 5-6

of queue formation should have the opposite trend in the two cases. This observation is true and may easily be verified by examining the results shown in Figs. 5-1 and 5-5 and Figs. 5-3 and 5-6.

Next, it is of interest to explain why the best efficiency obtained for the customer waiting time is substantially less than the best efficiency obtained for the time that the server remained idle.

The best efficiency for w is obtained when there is a queue in the system, for the reasons given earlier. Now because equation (5.24), the mathematical model for w , has no memory of the behavior of previous customers whereas w does, it is expected that the d characterization of w even at its best will not be entirely correct. On the other hand, the best efficiency for b is obtained when there is no queue in the system, for the reasons given earlier. Even though equation (5.55), the mathematical model for b , similarly has no memory of the behavior of previous customers, it is fortunate that neither does b , as it depends upon the service characteristics of the customer currently being served. For this reason, it is expected that under such circumstances d offers an excellent characterization of b , and hence it is expected that almost perfect negative correlation will be achieved between b' and b'' by negatively correlating d' and d'' . This may easily be verified by examining the results shown in Figs. 5-1 and 5-5 and Figs. 5-3 and 5-6.

Finally, we may deduce by logical argument that as ρ or σ_i^2 (and σ_s^2) increases, the likelihood of a queue formation increases, regardless of the distributions used to model the customer interarrival and service times. Then because the above conclusions are based only on the presence or absence of a queue in our system*, we may extrapolate our findings from the above and conclude that, in general, as the likelihood of queue formation in our system increases, then for the reasons given above the efficiency of our methodology decreases.

In the author's opinion it is advisable for the user to employ the suggested technique for negatively correlating b' and b''

i) even in cases where the efficiency is expected to be low, as the transformations involved are simple and non time consuming, and the experimental results have always yielded efficiencies never less than 1,

ii) because the transformations for negatively correlating w' and w'' and b' and b'' are the same, then if the user is interested in both w and b , he is always guaranteed extremely favorable results in one case or favorable results in both cases, regardless of the characteristics of our system.

*Remember that transformations given by equations (5.42), (5.43), (5.50) and (5.51) were derived for arbitrary $F^x(x_0)$ and $G^y(y_0)$ (see the discussion of equations (5.19) and (5.20^y)).

The above completes our discussion on the introduction of antithetic variance into the calculation of μ_b and σ_b^2 . Now, we proceed with our analysis by discussing the way that antithetic variance may be applied in the calculations of μ_c and σ_c^2 .

(c) Introduction of the Concept of Antithetic Variance into the Calculations of μ_c and σ_c^2 . (Closure Time)

As in the two cases discussed earlier, we are also attempting here to obtain two streams of dependent observations c_i' (time to serve K customers) and c_i'' ($i=1,2,\dots,n$) such that

$$\text{cov}(c', c'') \leq 0 \quad (5.59)$$

$$\text{Now because } c' = f_1(\xi', \zeta') \quad (5.60)$$

$$\text{and } c'' = f_2(\xi'', \zeta'') \quad (5.61)$$

where ξ' , ζ' , ξ'' and ζ'' are the only parameters which we control, we may postulate that our requirement is that of seeking the relationship between ξ' , ζ' , ξ'' and ζ'' that will yield such c' and c'' that satisfy equation (5.59). Unfortunately, as in the previous two cases, equations (5.60) and (5.61) allow no mathematical manipulation other than one that is very simple in nature. For this reason, in order to continue, we must mathematically model c in such a manner that mathematical manipulation is possible on the resulting equations, thus the required relationship between ξ' , ζ' , ξ'' and ζ'' that will yield negatively correlated c' and c'' .

The mathematical model that we selected for c in this study is given by the following equation:

$$d = \sum_{k=1}^K (x_k - y_k) \quad (5.62)$$

where d is used to characterize the time required to serve K customers.

Before proceeding, it is essential that we understand the limitations of our mathematical model (equation 5.62), as this understanding is necessary for the result interpretation presented later in this section.

First, we observe that for a large x and a small y , (the condition for a queue dispersion), d characterizes c efficiently because both d and c follow the same trend, namely, both assume algebraically large values. Second, we observe that for a small x and a large y (the condition for a queue formation), d characterizes c poorly because although c tends to assume an algebraically large value, d will tend to assume an algebraically small value. From this, we may conclude that when conditions are such that a queue is not likely to be formed in our system, by negatively correlating d' and d'' we achieve (indirectly) a higher degree of negative correlation between c' and c'' than when a queue is likely to be formed, because d characterizes c better in the former case than in the latter.

It is of interest to note (and it will also be helpful in the result interpretation to be presented later) that the

mathematical model for w (see equation 5.24) characterizes the customer waiting time best when there is a queue in our system, while the mathematical models for b and c (see equations 5.55 and 5.62) characterize best the time that the server remained idle and the closure time when there is a tendency for a queue dispersion in our system.

Finally, because equation (5.62) is of similar nature to equations (5.24) and (5.55), the comments on misalignment discussed in connection with equation (5.24) apply here too.

In summary, we have proposed to model equations (5.60) and (5.61) by equation (5.62), i.e.,

$$c' \text{ modeled by } d' = \sum_{k=1}^K (x'_k - y'_k) = \sum_{k=1}^K \left(\phi(\xi'_k) - \psi(\zeta'_k) \right) \quad (5.63)$$

$$c'' \text{ modeled by } d'' = \sum_{k=1}^K (x''_k - y''_k) = \sum_{k=1}^K \left(\phi(\xi''_k) - \psi(\zeta''_k) \right) \quad (5.64)$$

and then we have proposed to find the relationship between ξ' , ζ' , ξ'' and ζ'' so that

$$\text{cov}(d', d'') \leq 0 \quad (5.27)$$

anticipating (to be proved experimentally later) that this will also yield such c' and c'' that equation (5.59) will also be satisfied, because d models the behavior of c , with the limitations mentioned earlier.

Now if we continue along the same lines as we did in the previous case, we find that the necessary transformations to yield negatively correlated d' and d'' (see equations 5.63 and 5.64) are:

$$\xi'' = 1 - \xi' \quad (5.42)$$

$$\text{and } \zeta'' = 1 - \zeta' \quad (5.43)$$

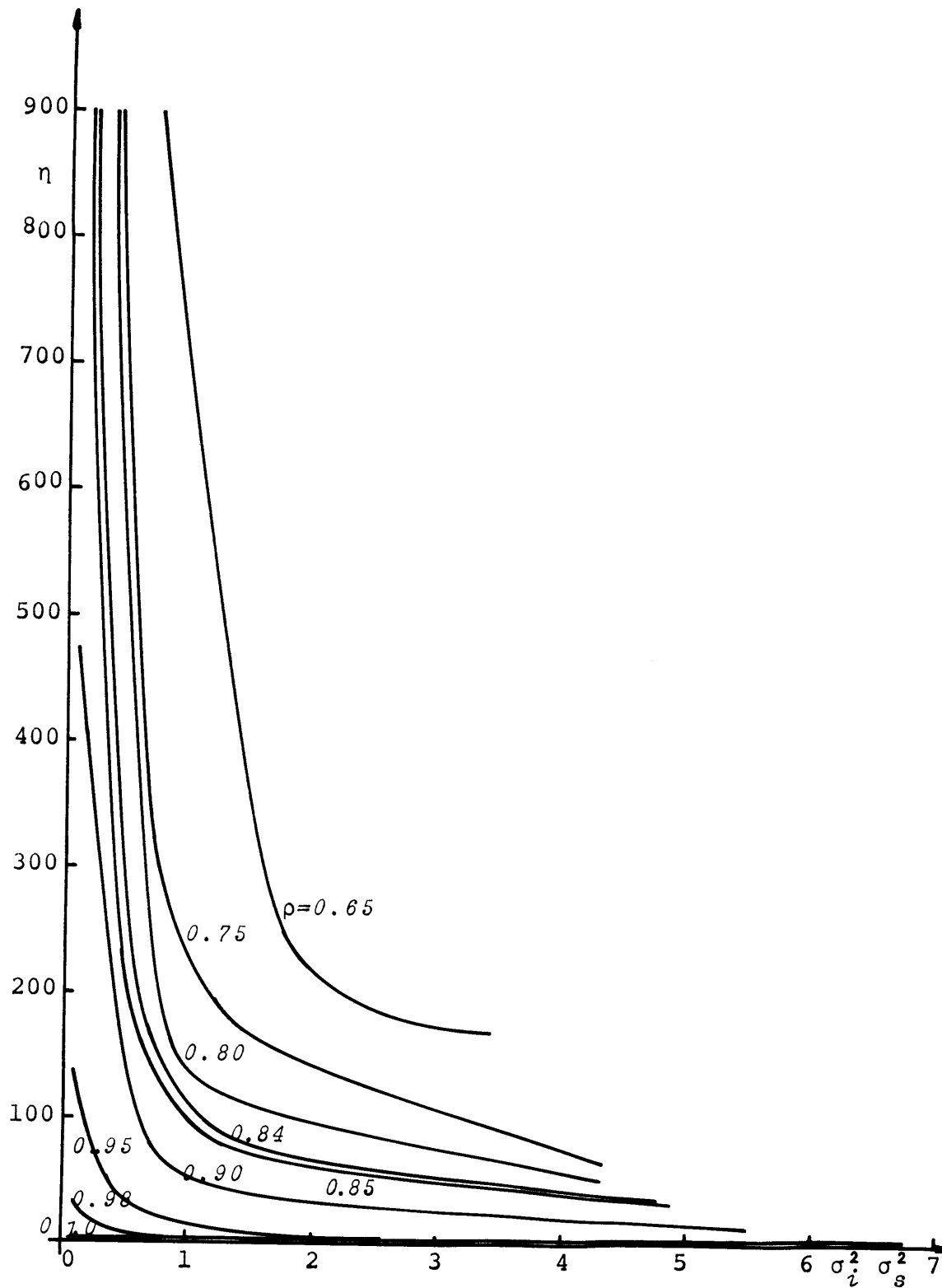
$$\text{or } \xi'' = \zeta' \quad (5.50)$$

$$\text{and } \zeta'' = \xi' \quad (5.51)$$

In Figs. 5-7 and 5-8 is shown the experimental proof that by negatively correlating d' and d'' (see equations 5.63 and 5.64), using the transformations given by equations (5.42 and (5.43), we also achieve a certain degree of negative correlation between c' and c'' .

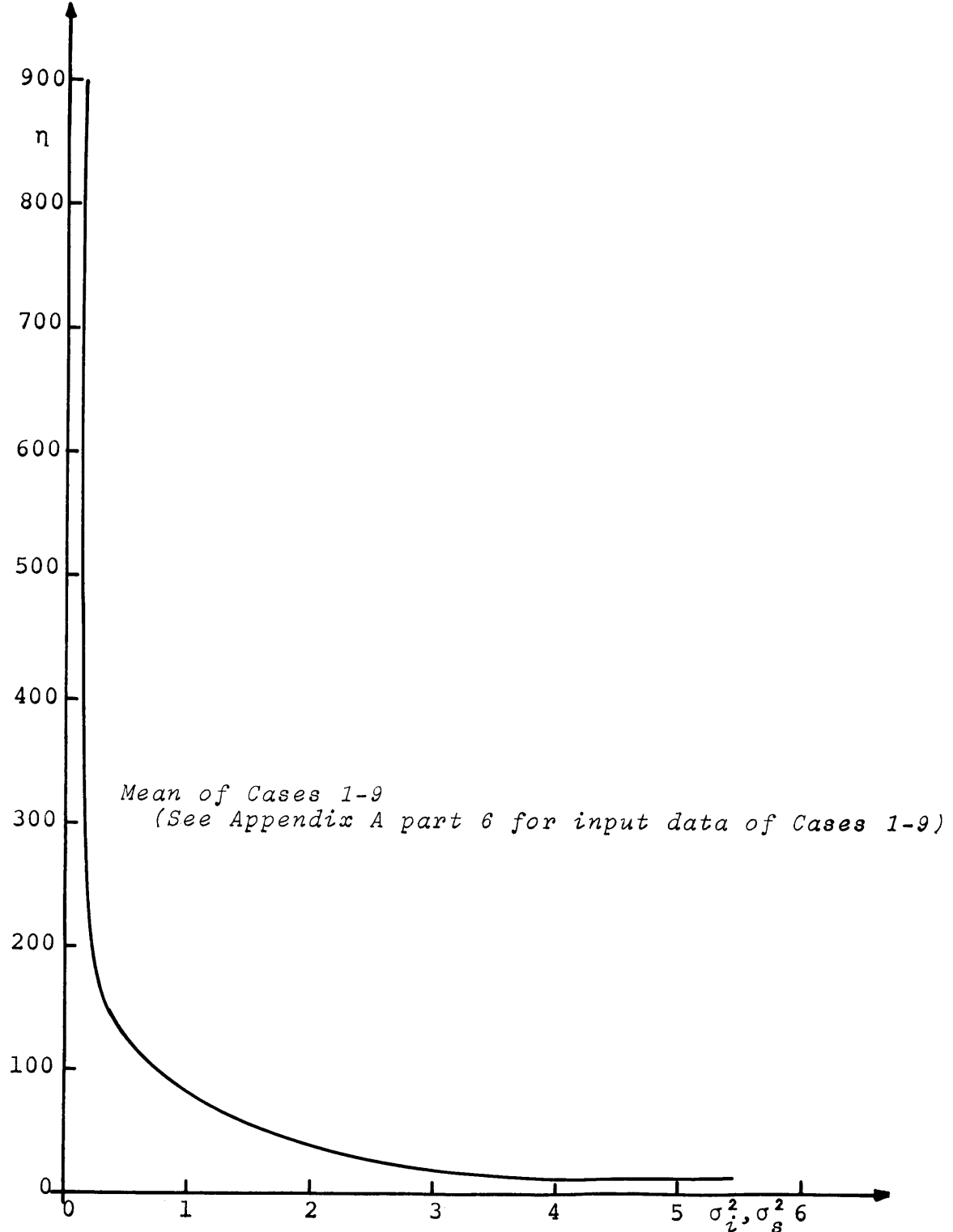
Because the results shown in Figs. 5-7 and 5-8 are similar in nature to those shown in Figs. 5-5 and 5-6, and because the mathematical model limitations for b and c are identical, then the conclusions given when we were discussing b are applicable here too.

With the above we have completed our discussion on the introduction of antithetic variance into the calculation of the statistics of interest for a one queue one server system. Now, we proceed with our analysis by discussing the way that antithetic variance may be applied in the calculation of the statistics of interest in more complex systems.



1Q-1S System Mean Time to Serve 200 Customers
 (η vs σ_i^2 and σ_s^2)

Fig. 5-7



1Q-1S System Mean Time to Serve 200 Customers for $\rho=0.90$
(η vs σ_i^2 and σ_s^2)

Fig. 5-8

iii) Introduction of the Method of Antithetic Variance into General Congestion Systems

If we were to apply the knowledge that we have gained from our previous analysis in more complex congestion systems, it is only reasonable to expect that if we wish to introduce the concept of antithetic variance into such systems, we should proceed in the following manner.

First, if " a " is the statistic of interest we should attempt to obtain two streams of observations a' and a'' such that

$$\text{cov}(a', a'') \leq 0 \quad (5.65)$$

$$\text{where } a' = f_1(\xi'_l, \zeta'_m) \quad (5.66)$$

$$\forall l, m$$

$$\text{and } a'' = f_2(\xi''_l, \zeta''_m) \quad (5.67)$$

$$\forall l, m$$

Second, we should attempt to mathematically manipulate equations (5.66) and (5.67) in order to derive a relationship between ξ' , ζ' , ξ'' and ζ'' (these being the only parameters that we are able to control) that will yield such a' and a'' that satisfy equation (5.65).

Finally, noting that equations (5.66) and (5.67) allow no mathematical manipulation other than one that is very simple in nature (a characteristic of congestion problems), we should attempt to mathematically model " a " in such a manner that will allow the derivation of the required relationship (between ξ' , ζ' , ξ'' and ζ'') that will lead to negatively

correlated a' and a'' .

162.

If a model, d , similar to those given by equations (5.24) or (5.55) or (5.62) is selected, then it can be shown mathematically that one type of the required transformations that give negatively correlated d' and d'' for all three statistics of interest is:

$$\xi''_{\ell} = 1 - \xi'_{\ell} \quad \forall \ell \quad (5.68)$$

$$\text{and } \zeta''_m = 1 - \zeta'_m \quad \forall m \quad (5.69)$$

In that case, the following general guidelines may be offered to the user regarding the usefulness of antithetic variance in general congestion systems.

a) Customer Waiting Time, w .

If the characteristics of our system are such that no queues are expected to be formed, the efficiency of our methodology is expected to be very low (but not less than 1) and so the return on our effort is not expected to be great. However, if the characteristics of our system are such that queues are likely to be formed, the efficiency of our methodology is expected to be good, and so the user is encouraged to use it. The reason for this statement, as was explained in our earlier discussion, is that when there are queues in our system, d models w more correctly than when there are no queues in our system. If that is the case, the method of negatively correlating d' and d'' should also yield (indirectly) a better negative correlation between w' and w'' in the former case than in the latter.

If the characteristics of our system are such that no queues are expected to be formed, the efficiency of our methodology is expected to be very good and so the user is encouraged to use it. However, if the characteristics of our system are such that queues are likely to be formed, the efficiency is expected to be lower (but not less than 1), and so the return on our effort is not expected to be as great. The reason for this statement, as was explained in our earlier discussion, is that when there are no queues in our system, d models b (and c) more correctly than when there are queues in our system. If that is the case, then the method of negatively correlating d' and d'' should also yield (indirectly) a better negative correlation between b' and b'' (and c' and c'') in the former case than in the latter.

c) From the above discussion, it should be obvious that if the user is interested in all three statistics, it will be to his advantage to adopt the suggested methodology because he will always be rewarded in the calculations of at least one statistic, and will never be penalized in the calculation of the remaining statistic(s).

Before leaving the subject of guidelines to the user regarding the use of the method of antithetic variance in general congestion problems, it will be advantageous to discuss the consequences of the misalignment of customer interarrival

and service times in the two dependent streams of observations, and the technique for ensuring the proper alignment of these variables in order to maximize the efficiency of our methodology.

In order to discuss this topic, it is necessary to refer to one of the mathematical models (see equation (5.24) or (5.55) or (5.62)) presented earlier. If we choose, for example, the model given by equation (5.24), where d_j is used to characterize the waiting time of the j th customer, we observe that we are expected to achieve maximum efficiency if

$$\xi_j'' = 1 - \xi_j' \quad (5.70)$$

$$\zeta_j'' = 1 - \zeta_j' \quad (5.71)$$

i.e., the customer interarrival and service times in both streams of observations are related. This is so because if a misalignment occurs, we do not achieve with our transformation (see equations (5.70) and (5.71)) what we set out to do, namely, to match a sequence of customers arriving frequently and requiring a long service with a sequence of customers arriving at long intervals and requiring little service, and vice versa (see Appendix A, part 3, heuristic proof).

To substantiate the argument given above regarding misalignment, the following three experiments were performed.

Experiment Definition

System

Two queues feeding in one server through a single channel.

- i) Initialize system at the beginning of each run by emptying both queues and the server.
- ii) The service strategy is first come, first served.
- iii) Once a customer joins the queue during a sample run he cannot leave it.
- iv) The customer interarrival times for both queues are generated from two independent $U(0,1)$ distributions, and the customer service time is generated from a $U(0,0.5)$ distribution.
- v) The customer service time is independent of both customer interarrival times.

Experimental Details

- i) Each sample is to involve 200 observations, i.e., in each sample, 200 customers are to be served.
- ii) Each experimental value is to be computed from the results of 50 samples.
- iii) The starting value of the seeds for the first sample is 65539 for the interarrival time of the customer joining the first queue, 46293 for the interarrival time of the customer joining the second queue and 65533 for the customer service time.

In the first experiment, the results were obtained by first running 50 samples of 200 observations, each using

ξ_1 , ξ_2 , and ζ as the random variables, and then repeating the experiment using $(1-\xi_1)$, $(1-\xi_2)$ and $(1-\zeta)$ as the random variables.

In the second experiment, the results were obtained by first running the first sample of 200 observations using ξ_1 , ξ_2 and ζ as the random variables, and then repeating the experiment using $(1-\xi_1)$, $(1-\xi_2)$ and $(1-\zeta)$ as the random variables. At the end of this part of the experiment, the seeds of the two interarrival and service times were assigned new values (ensuring that the requirement of independence was satisfied) and then the experiment described above was repeated. This procedure was repeated until the 50 samples were completed.

In the third experiment, the j th customer was associated with a service time (ζ_j) during the execution of the samples, which were utilizing ξ_1 , ξ_2 and ζ as random variables. Then, when the sample utilizing $(1-\xi_1)$, $(1-\xi_2)$ and $(1-\zeta)$ as random variables was run, the j th customer's service time was $(1-\zeta_j)$.

From the above, it is clear that in the first experiment we have a very poor alignment of customers and service times, in the second experiment a better alignment, while in the third a perfect alignment.

The experimental results are shown below.

	<u>η for w</u>	<u>η for c</u>
Experiment 1	1.62	1.60
Experiment 2	2.05	2.76
Experiment 3	2.36	2.84

These results substantiate our observation, namely, that the efficiency of our methodology increases when the degree of aligning customers with service times in the ξ , ζ and $(1-\xi)$, $(1-\zeta)$ runs is increased.

Many methods exist for achieving the perfect alignment described in the third experiment. The most efficient method for achieving such an alignment is due to Prof. Sussman*, viz: a separate service generator (having the desired characteristics) is associated with each stream of oncoming customers feeding into a server. In this way, the bookkeeping needed for associating service times with customers is kept to a minimum, because the only information we need to know is with which queue the customer is associated. This is so because we have effectively reduced our problem to a conglomeration of 1Q-1S systems.

With the above, our discussion of the introduction of the concept of antithetic variance into congestion problems is complete, and so we now proceed by applying the findings of our analysis to the mathematical model of our study (see Section 4). The results obtained from this application, (which also serve to experimentally prove that the transformations given by equations (5.70 and (5.71) give $\eta > 1$ in complex congestion models) are presented in the next section.

*Joseph M. Sussman, Assistant Professor in the Department of Civil Engineering at the Massachusetts Institute of Technology, Cambridge, Massachusetts.

In this study, ten test cases of the problem under investigation were examined. The input data for these cases may be found in Table 6.1 and in Appendix B. The results obtained are shown in Tables 6.2-6.4. For the correct ordering of the input data, the user is referred to Figs. 6.1-6.18.

The input data for the cases examined here corresponds to hardware (T.V., S.U.F., B.U.F. and standard containers) already in existence, and because of budgetary limitations no cases involving hypothetical hardware were examined. In addition, the input data used in this study corresponds to an assumed sea state, 2, and that data which is affected by environment (see Section 3) reflects this assumption.

It is of importance to note that unless the study is being used for the evaluation of a system involving novel hardware (where output regarding the system's state at intermediate stages is helpful and necessary), it is advisable to suppress any intermediate output that the program (see Appendix C) gives in order to

- i) make the algorithm more economical to use, or to
- ii) allow, at the same expense, the investigation of alternative use strategies, which will lead to the more confident establishment of the set of "optimum" use strategies, or to

iii) permit, at the same expense, the execution of more runs per case, which will lead to the estimation of the statistics of interest with higher confidence.

The above completes our discussion regarding the problem solution, and we may now proceed with the evaluation of the results obtained in this study (see Tables 6.2-6.4).

Table 6-1.
Experimental Data for the Digital Simulation
of a Transportation Interface.
Test Cases.

Case No.	ID of T.V. Used	ISUD	IBUD	IWA1SL	IWA2SL	ISCSL	IBCSL	ICHANG
1	1,2...5	1	1	1	1	2	2	1
2	1,2...6	1	1	1	1	2	2	1
3	1,2...7	1	1	1	1	2	2	1
4	1,2...8	1	1	1	1	1	1	1
5	1,2...8	1	1	2	2	1	1	1
6	1,2...8	1	1	1	1	2	2	1
7	1,2...8	1	1	2	2	2	2	1
8	1,2...8	1	1	3	3	2	2	2
9	1,2...8	1	1	5	1	3	2	1
10	1,2...8	1	1	5	1	2	2	1

Table 6-2.
Mother Ship's Closure Time*

Case No.	Mean **	Variance	Efficiency
1	1124.5	65.3	1.25
2	885.4	59.5	1.12
3	743.2	201.9	1.02
4	691.5	34.1	1.85
5	690.5	28.9	1.82
6	692.6	19.9	2.11
7	692.7	31.8	1.84
8	697.3	35.8	1.32
9	669.9	173.8	1.22
10	684.9	30.1	1.86

*For the definition of Closure Time, see the discussion given in connection with equation 3.18.

**Units of Time: Minutes

Table 6-3.
Beach Unloading Facilities' Closure Time*

Case No.	Mean**	Variance	Efficiency
1	1158.4	59.6	1.27
2	921.2	45.2	1.20
3	779.2	148.2	1.12
4	735.4	46.2	1.59
5	734.8	36.1	1.41
6	727.6	18.4	2.02
7	728.1	30.9	1.52
8	728.7	30.8	1.22
9	706.8	183.3	1.15
10	719.8	24.8	1.69

*For the definition of Closure Time, see the discussion given in connection with equation 3.18.

**Units of Time: Minutes

Table 6-4.
Transfer Vehicles Closure Time*

Case No.	Mean**	Variance	Efficiency
1	1188.2	57.0	1.31
2	951.0	48.0	1.19
3	807.7	178.9	1.05
4	765.8	45.7	1.61
5	765.0	36.6	1.45
6	758.0	17.8	2.10
7	758.6	37.0	1.38
8	759.1	33.3	1.16
9	736.2	206.8	1.09
10	750.1	24.9	1.62

*For the definition of Closure Time, see the discussion given in connection with equation 3.18.

**Units of Time: Minutes

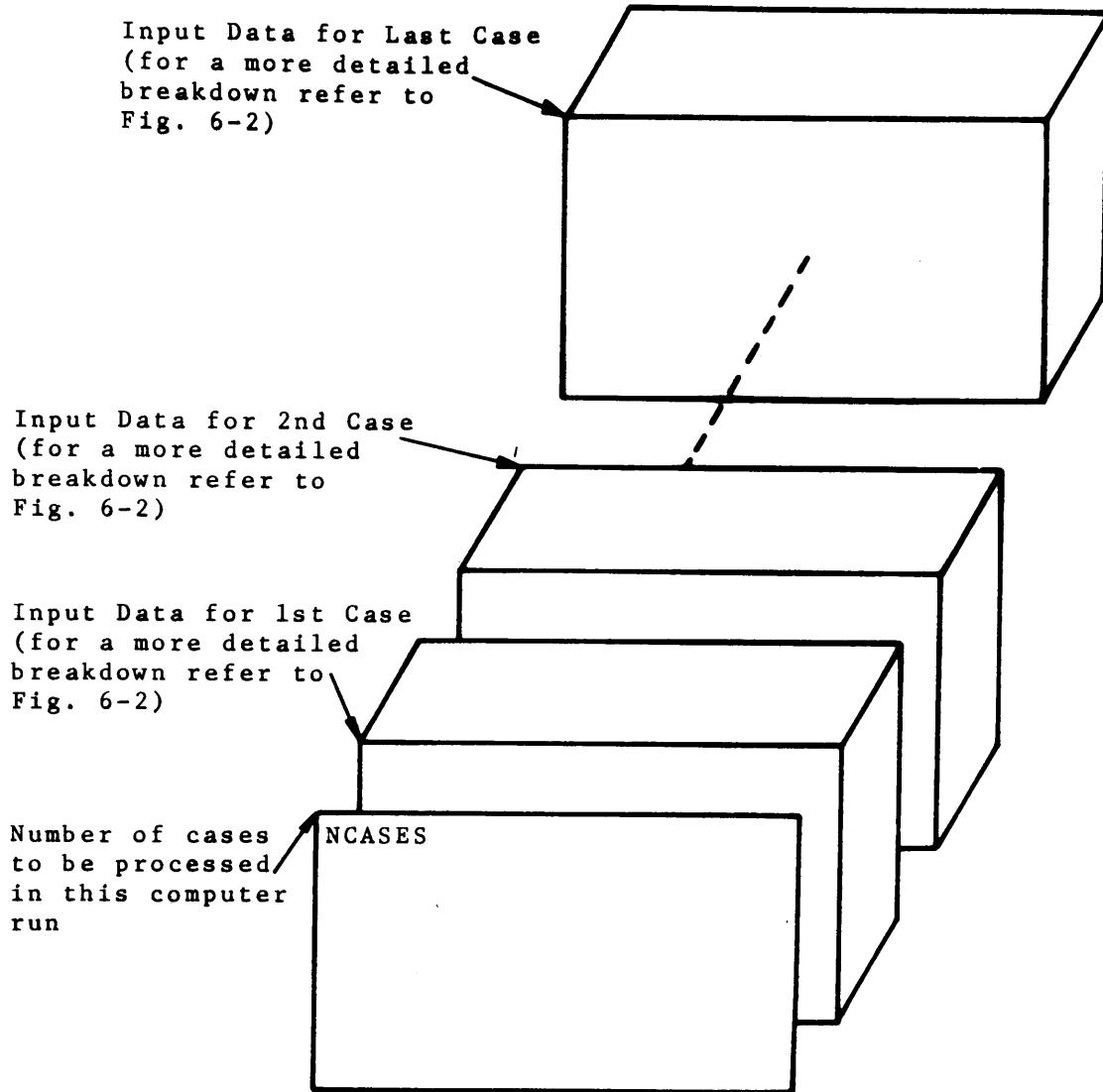


Fig. 6-1. General Data Setup

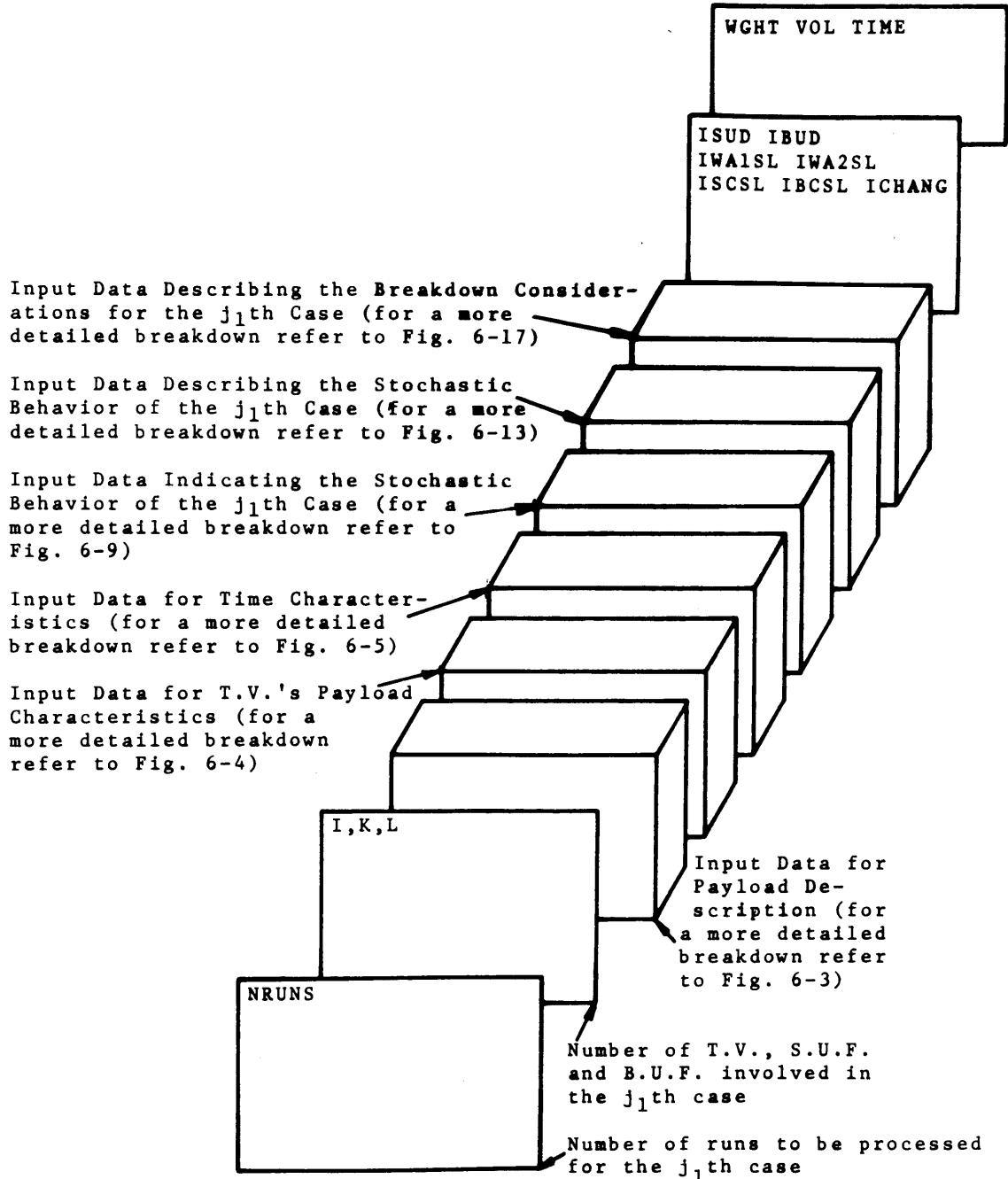


Fig. 6-2. Input Data Setup for the j_1 th Case ($j_1=1,2,\dots,NCASES$)

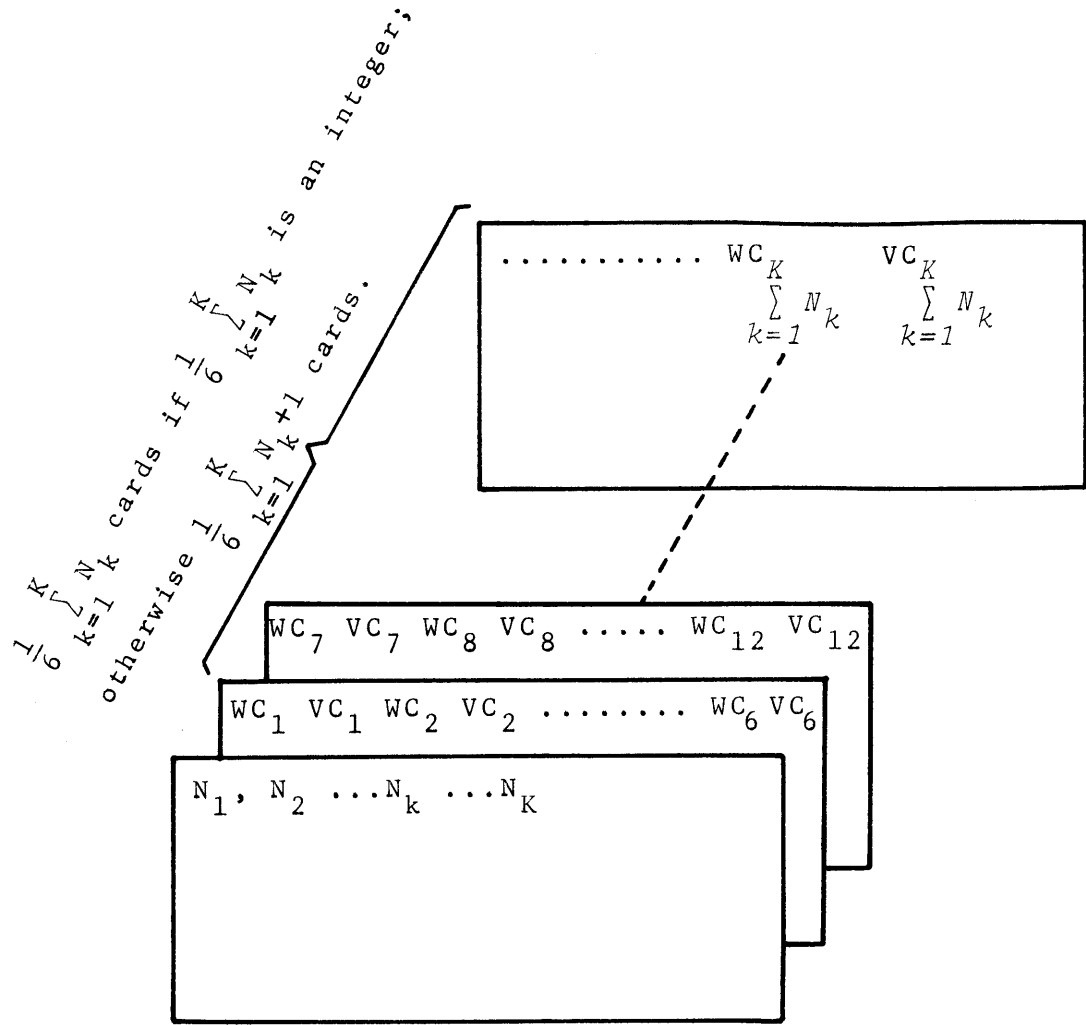


Fig. 6-3. Input Data Setup for the Payload Description

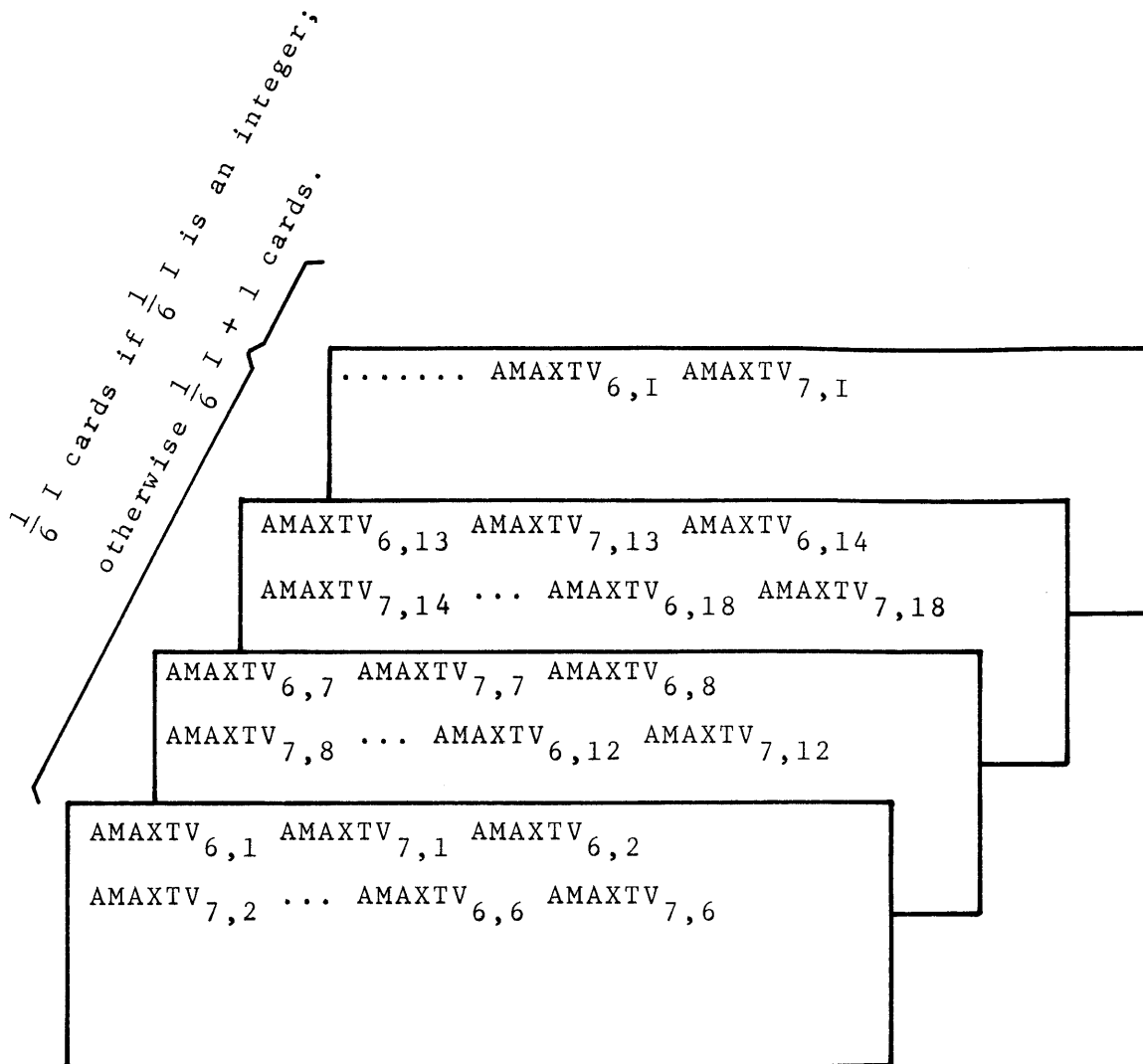


Fig. 6-4

Input Data Setup for the T.V.'s Payload Characteristics

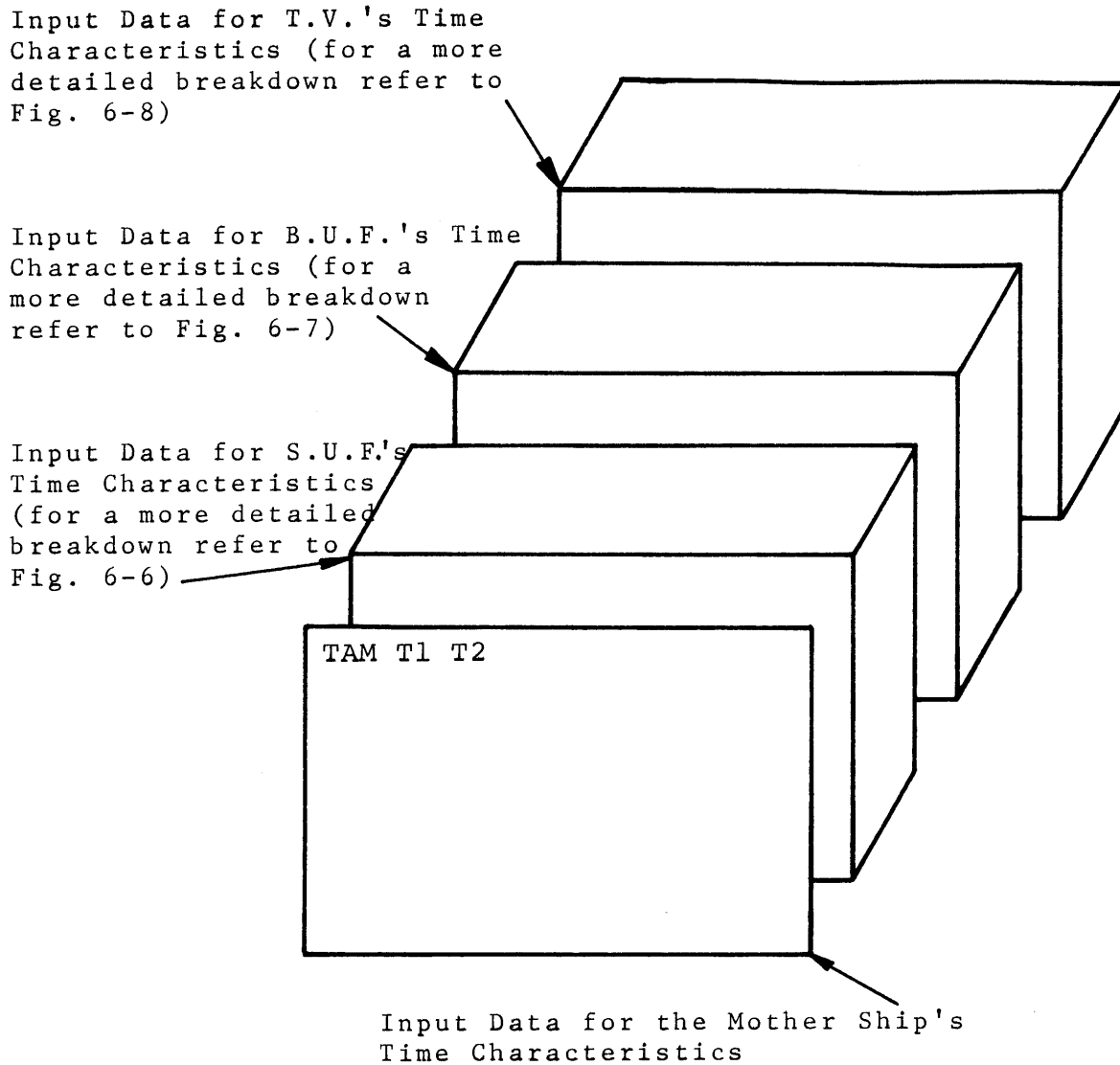


Fig. 6-5. Input Data Setup for the Time Characteristics

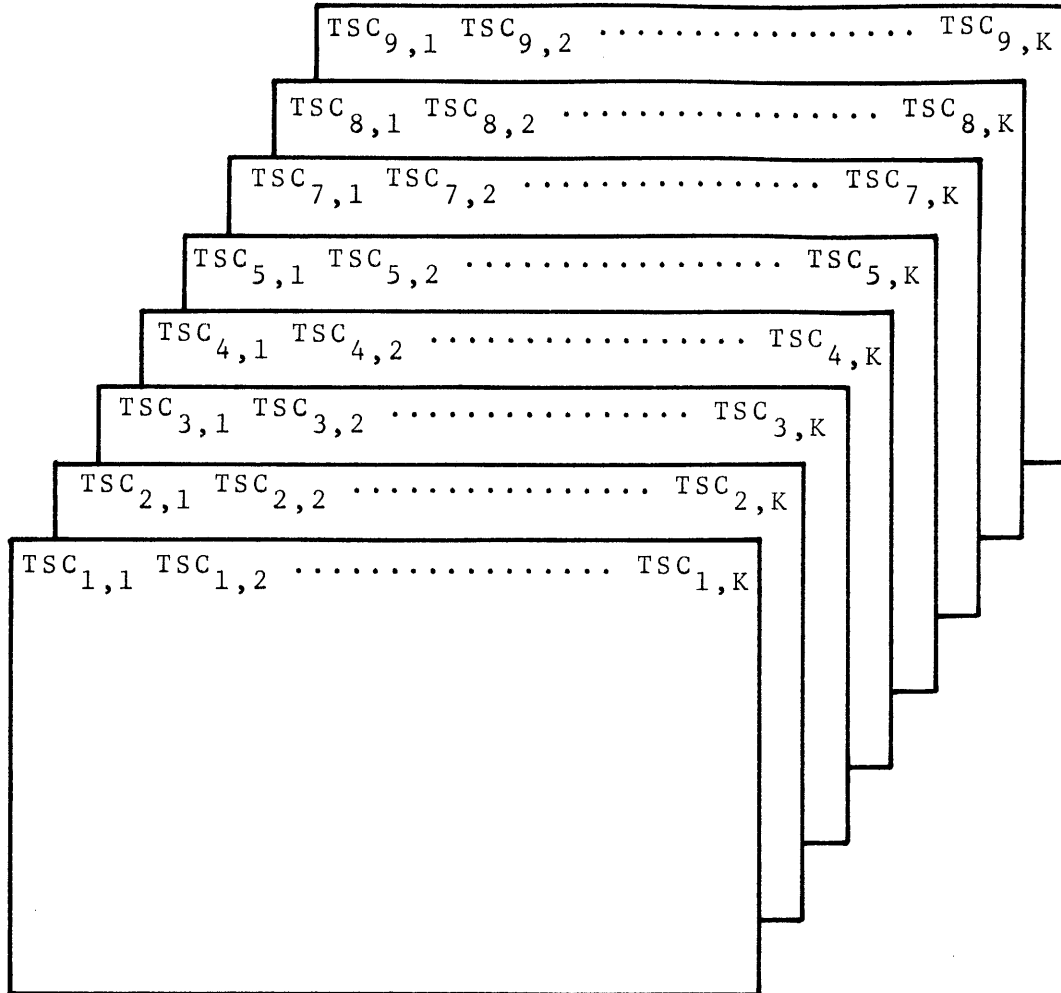


Fig. 6-6. Input Data Setup for the S.U.F.'s Time Characteristics

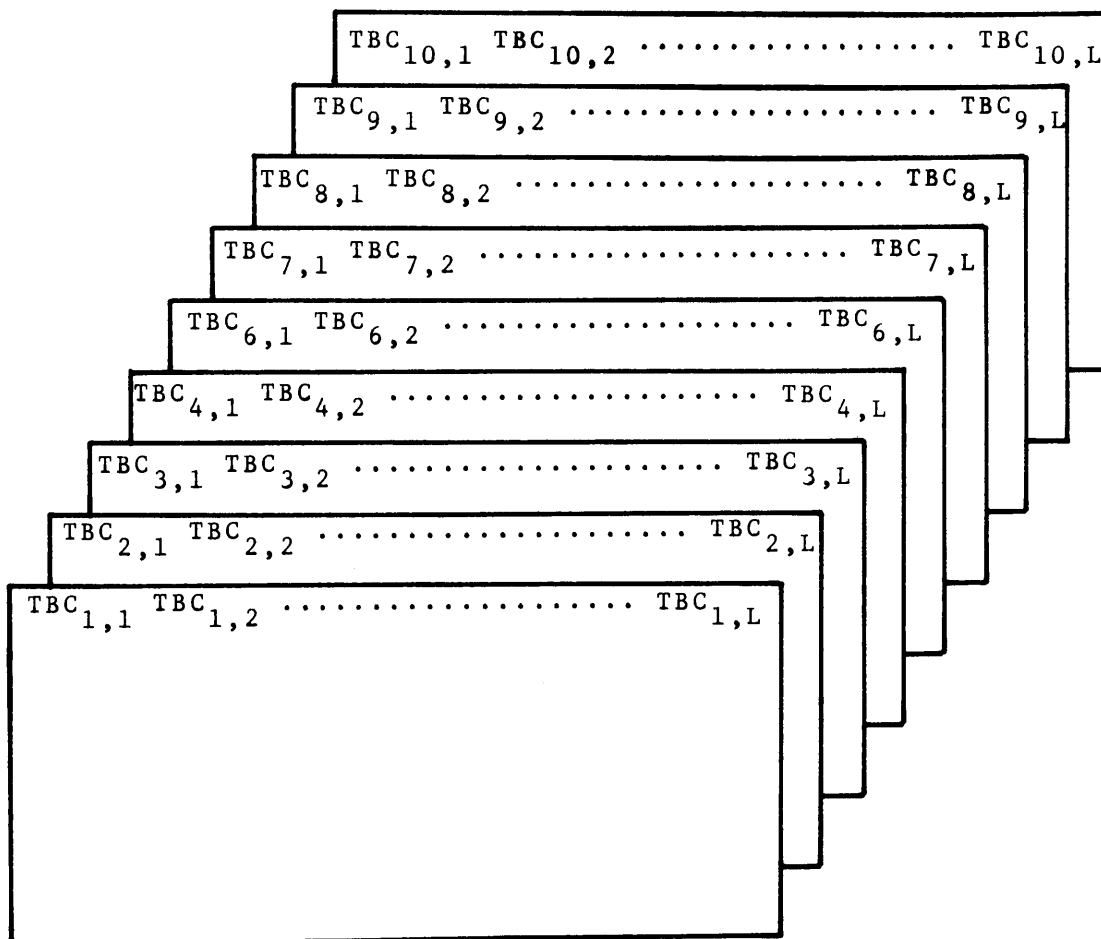


Fig. 6-7

Input Data Setup for the B.U.F.'s Time Characteristics

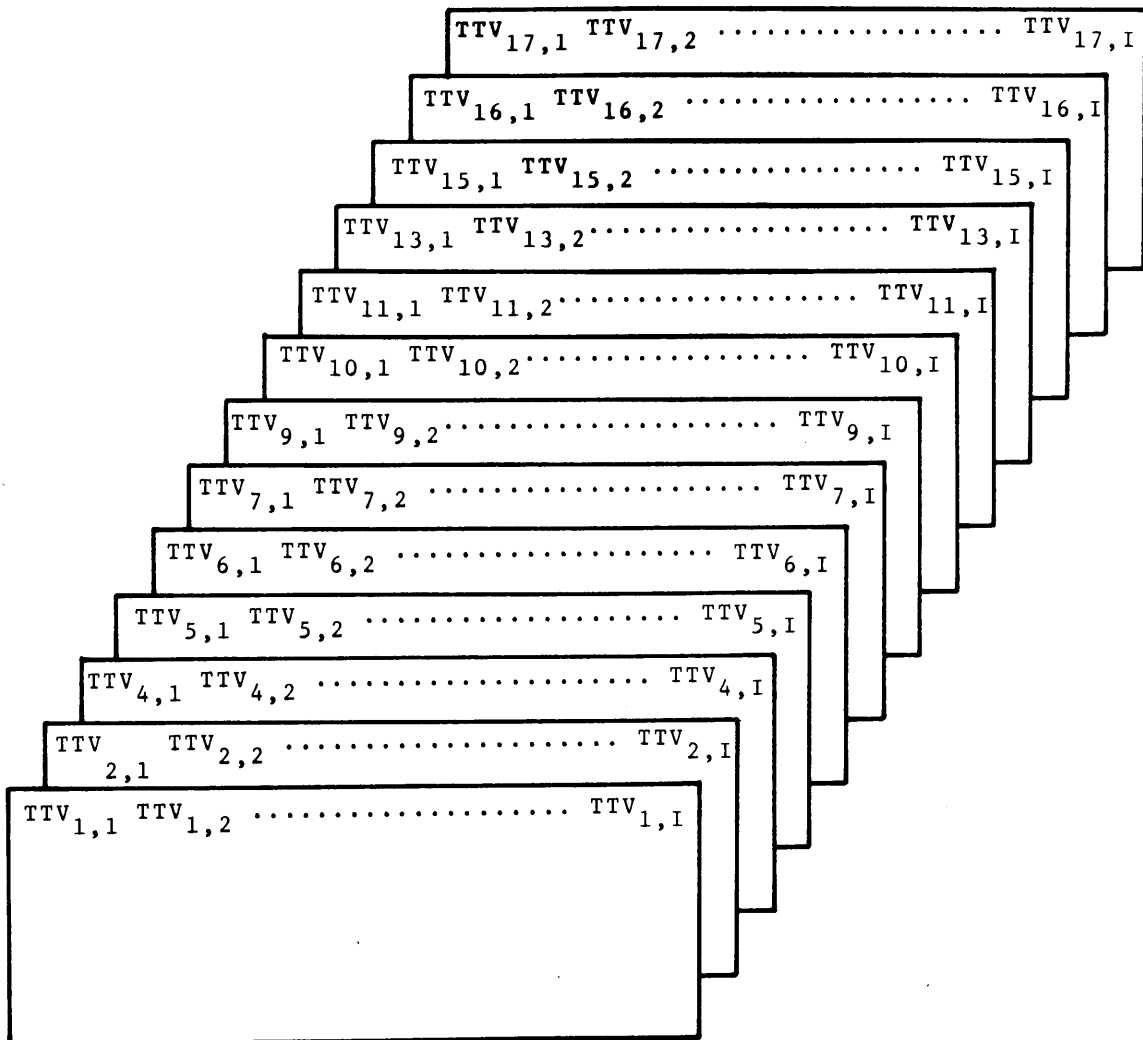


Fig. 6-8

Input Data Setup for the T.V.'s Time Characteristics

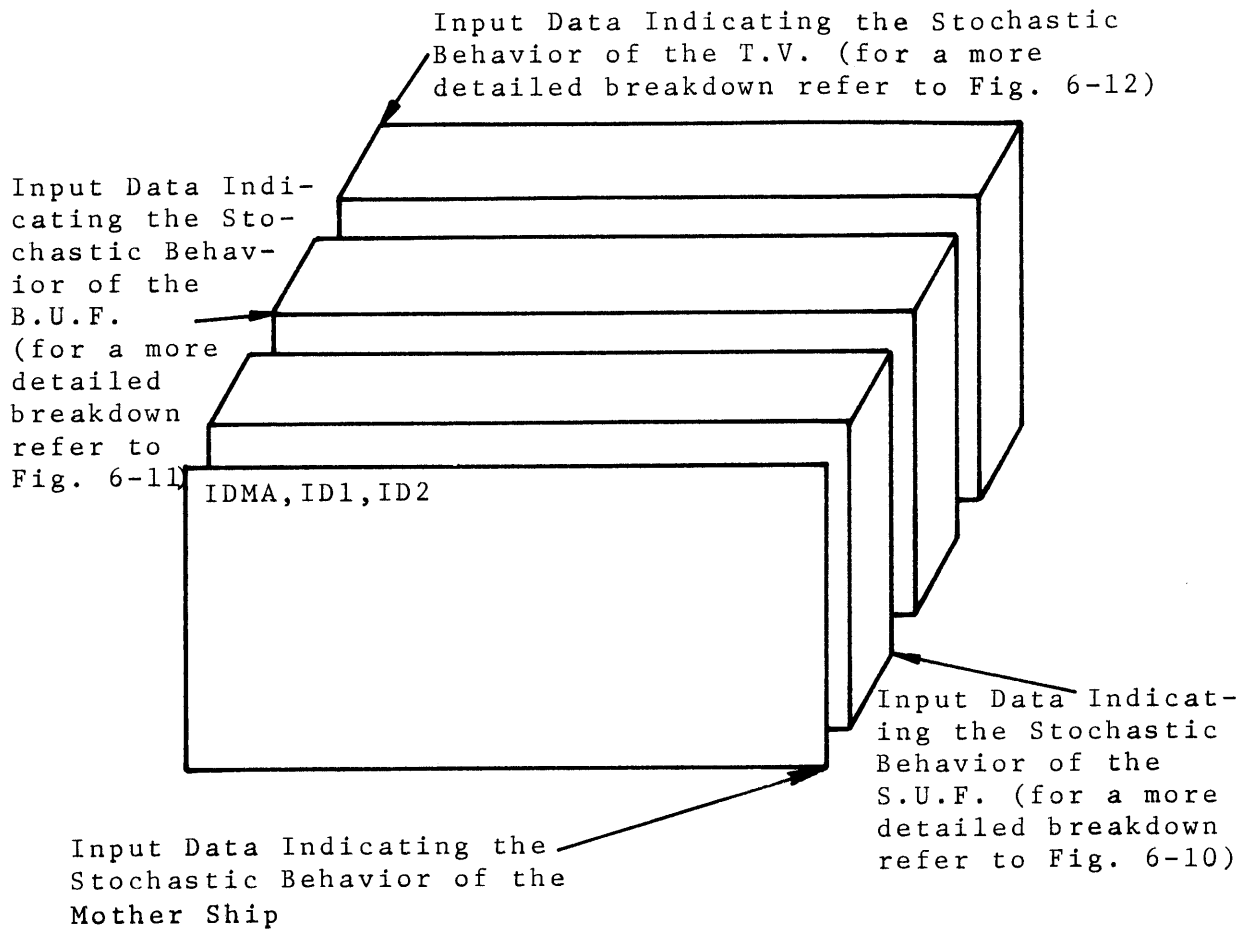


Fig. 6-9

Input Data Setup for the Indication of the Stochastic Behavior of the j_1 th Case

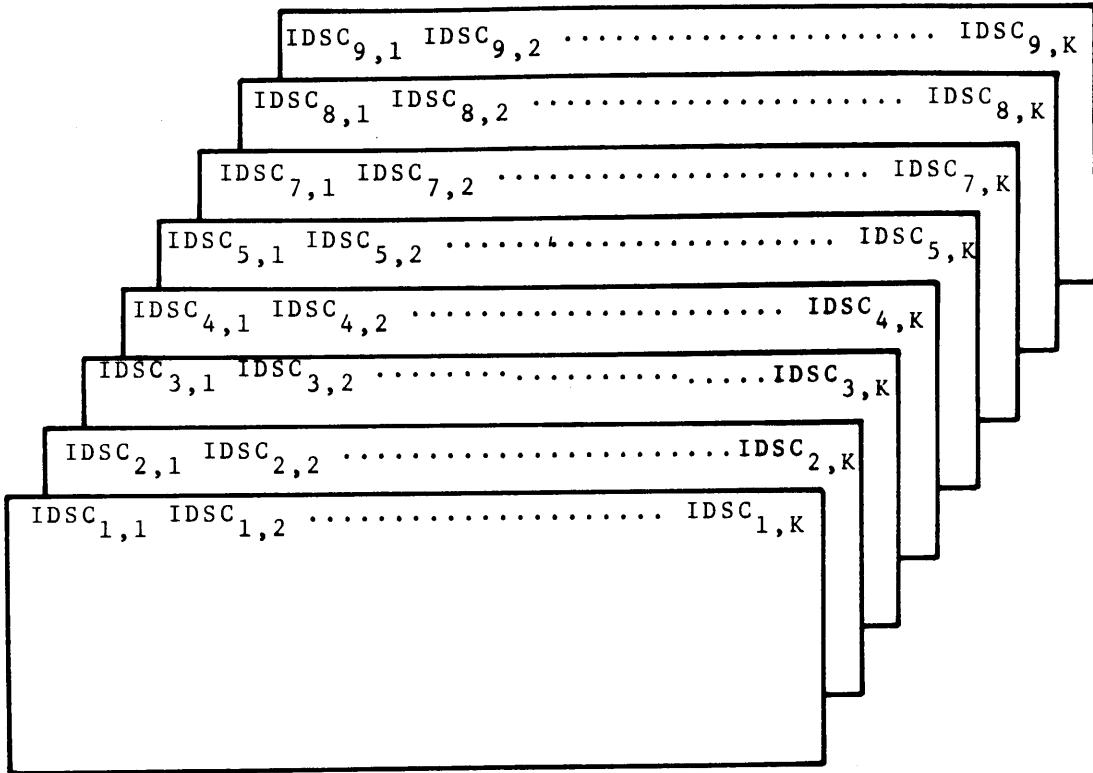


Fig. 6-10
Input Data Setup for the Indication of the
Stochastic Behavior of the S.U.F.

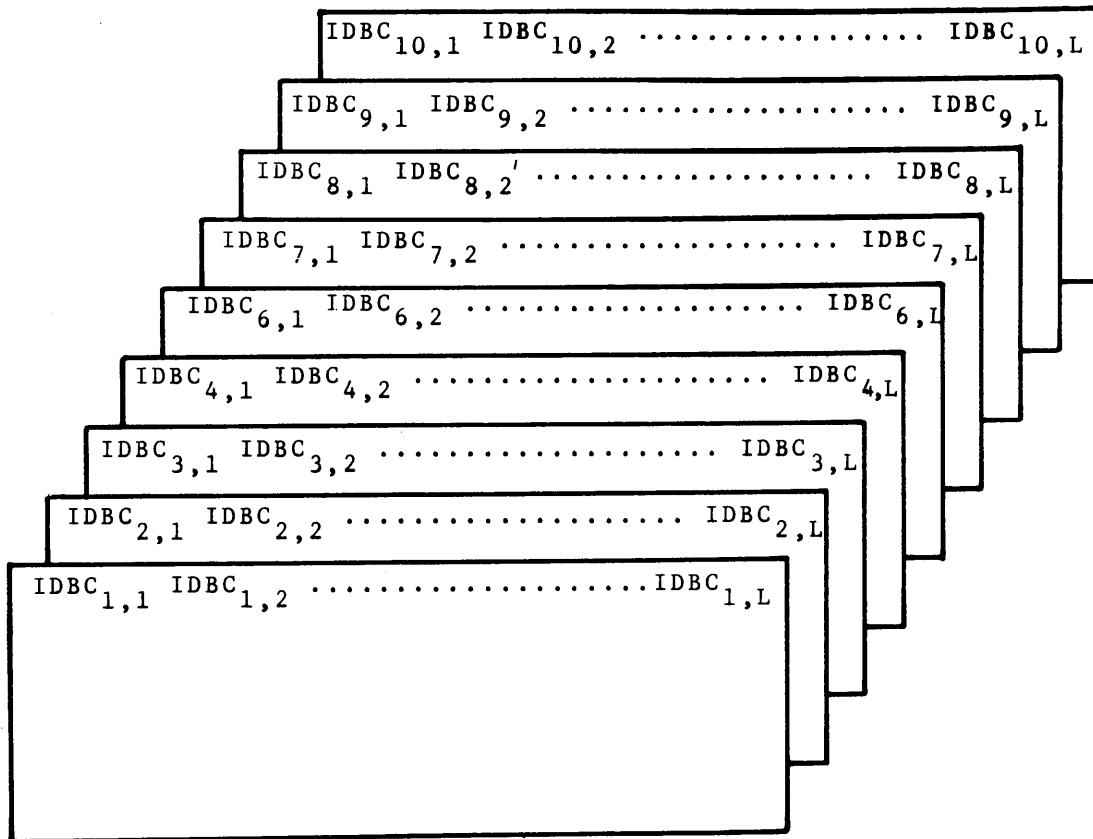


Fig. 6-11

Input Data Setup for the Indication of the
Stochastic Behavior of the B.U.F.

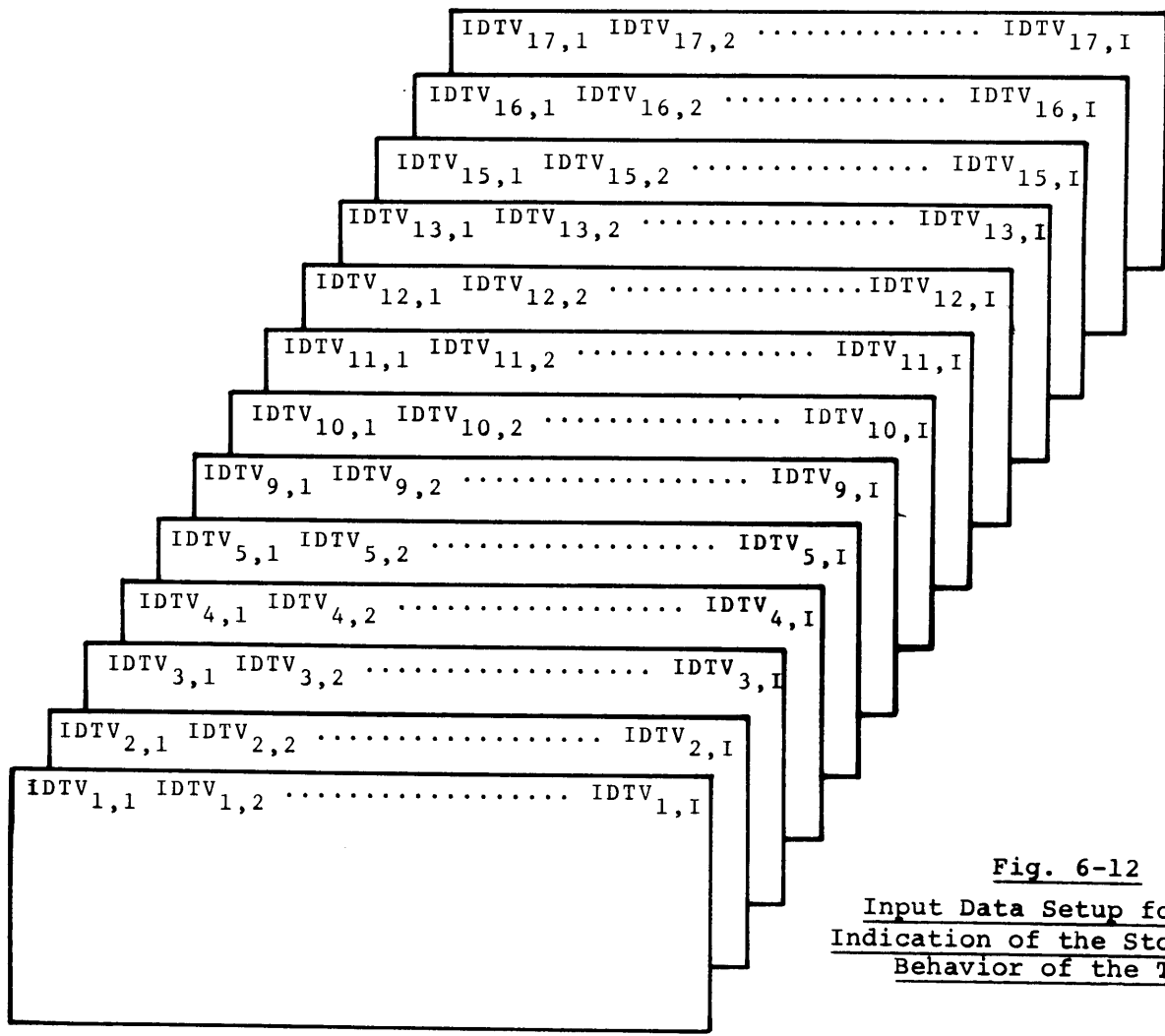


Fig. 6-12
Input Data Setup for the
Indication of the Stochastic
Behavior of the T.V.

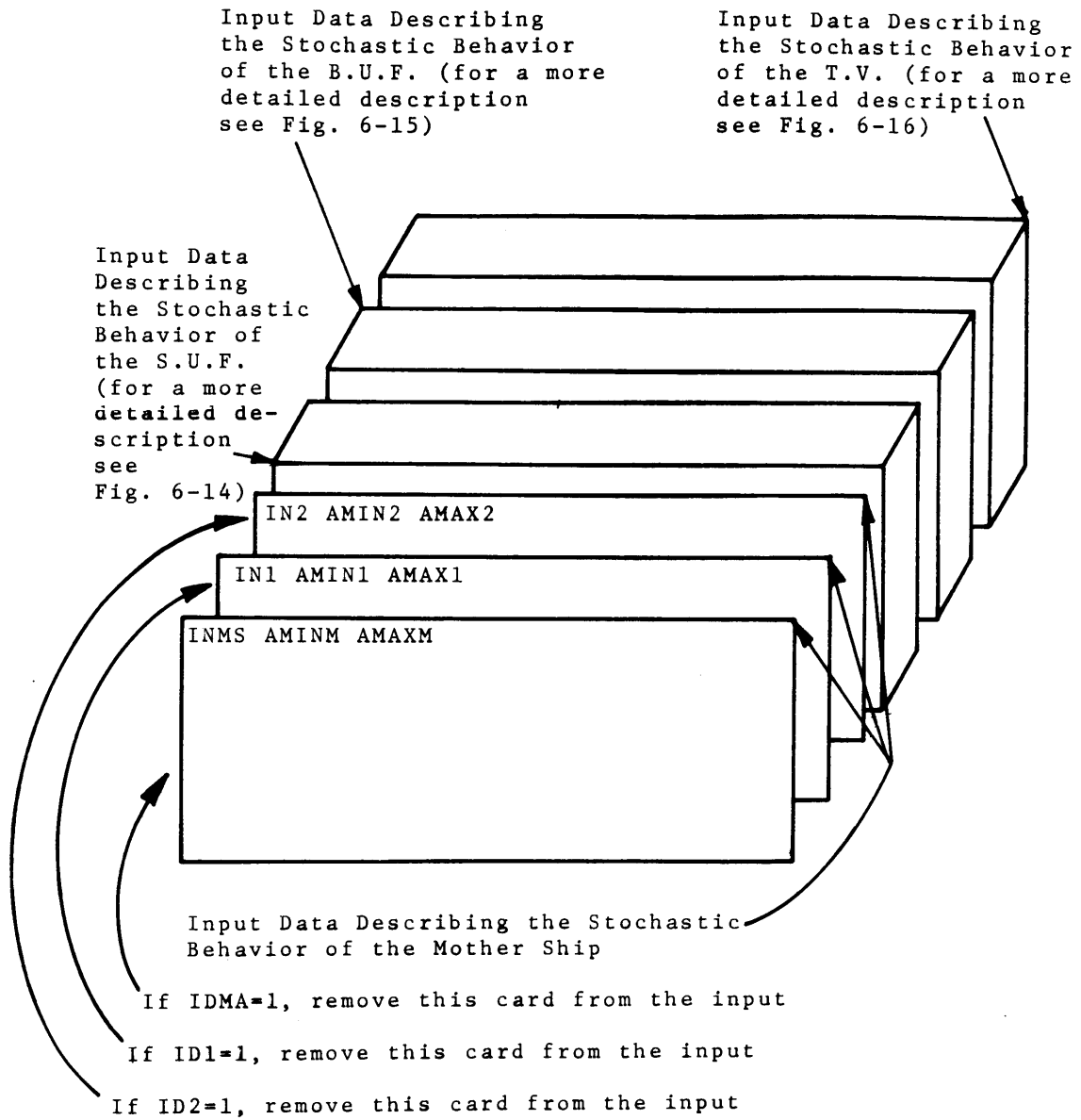


Fig. 6-13
Input Data Setup for the Description of
the Stochastic Behavior of the j_1 th Case

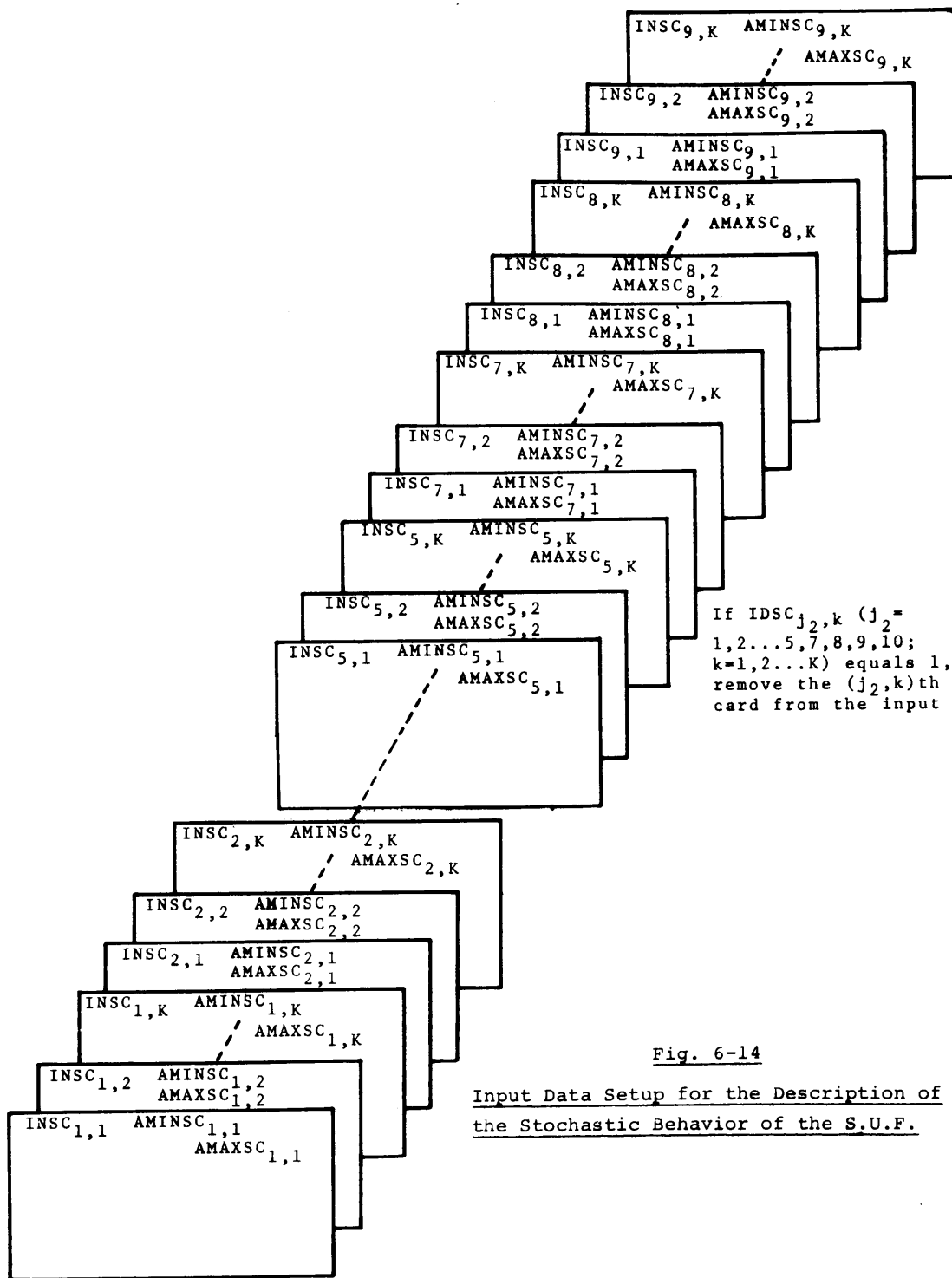


Fig. 6-14

Input Data Setup for the Description of the Stochastic Behavior of the S.U.F.

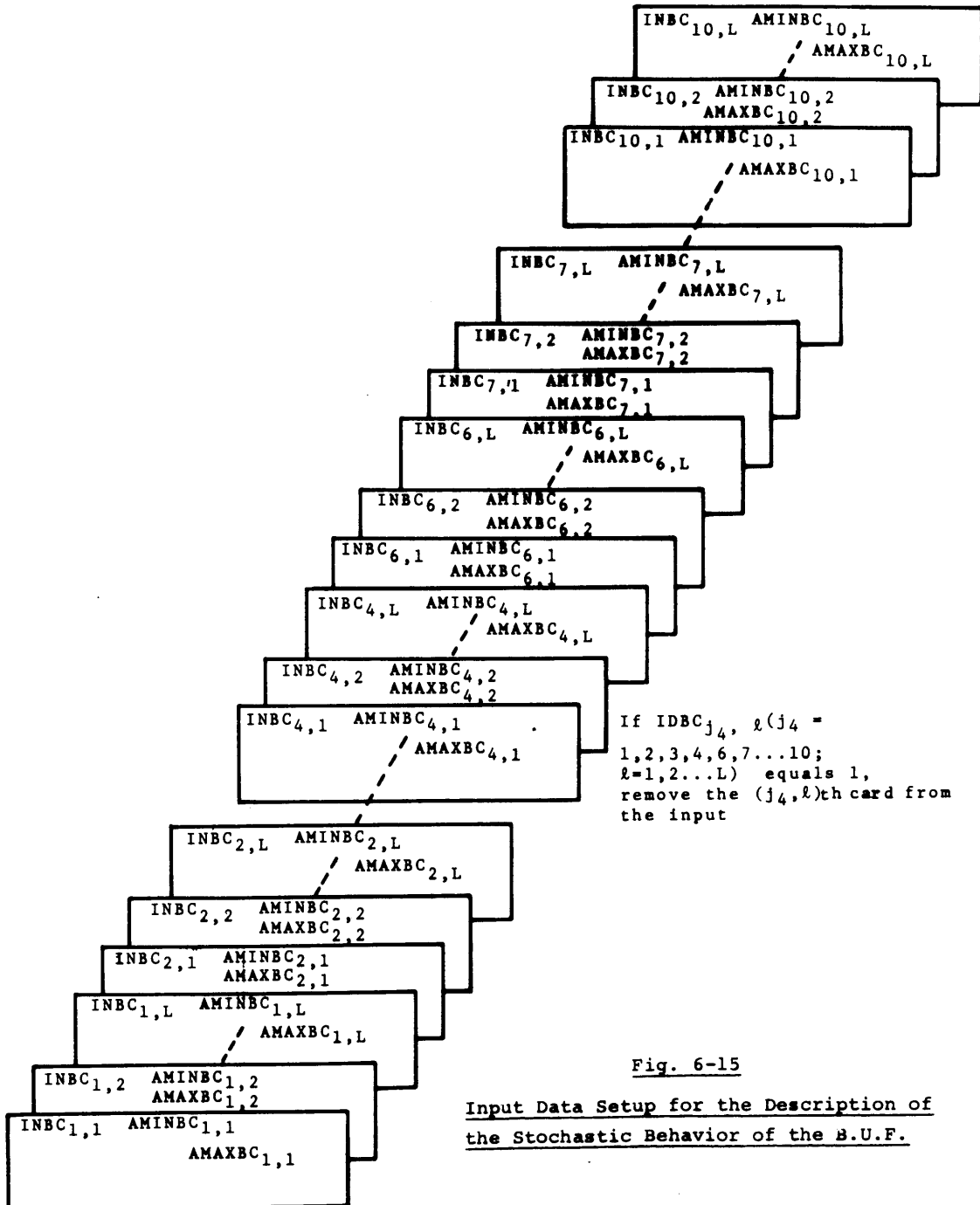


Fig. 6-15

Input Data Setup for the Description of the Stochastic Behavior of the B.U.F.

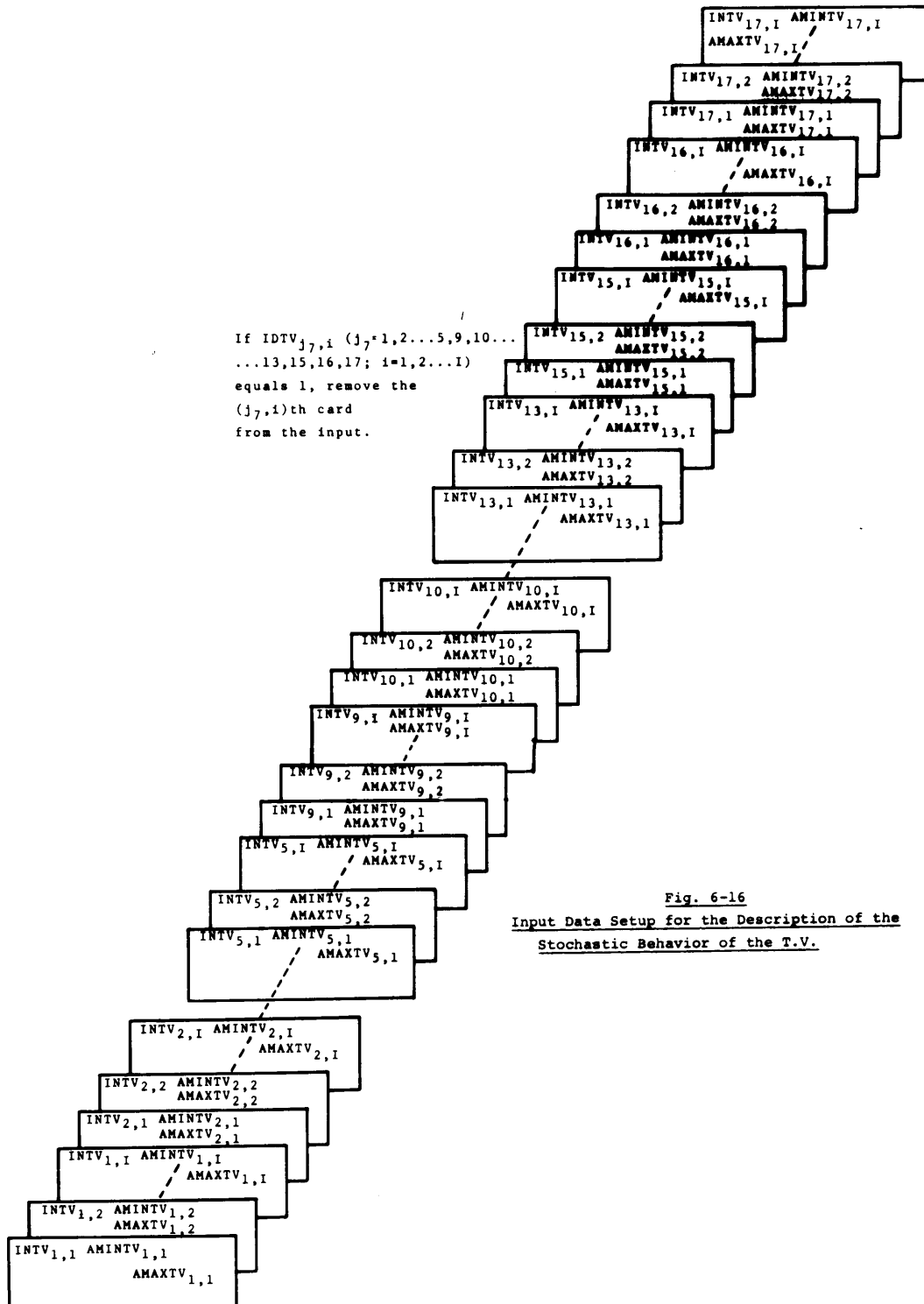


Fig. 6-16
Input Data Setup for the Description of the
Stochastic Behavior of the T.V.

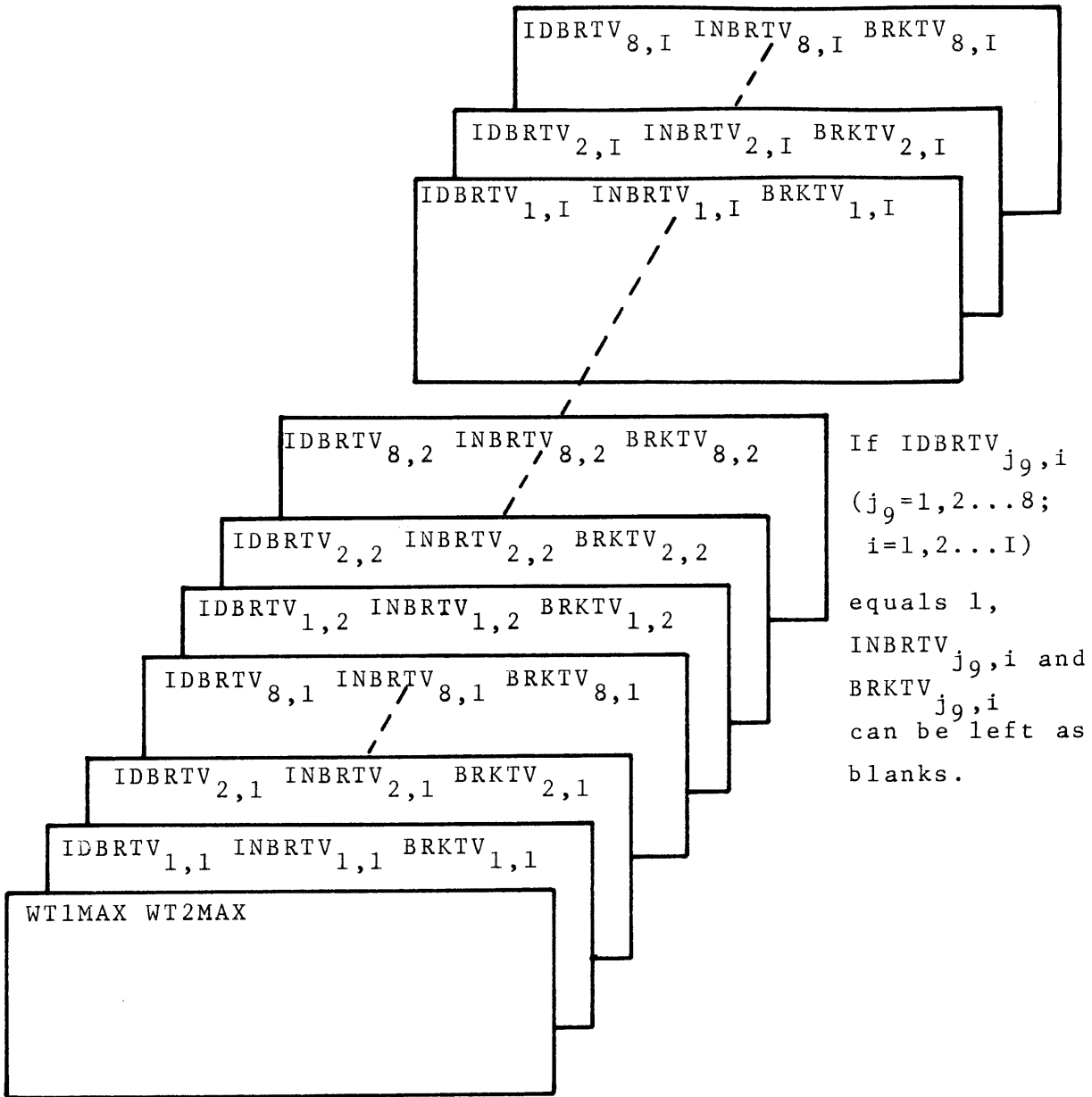


Fig. 6-17. Input Data Setup for the Description of the T.V.'s Breakdown Considerations

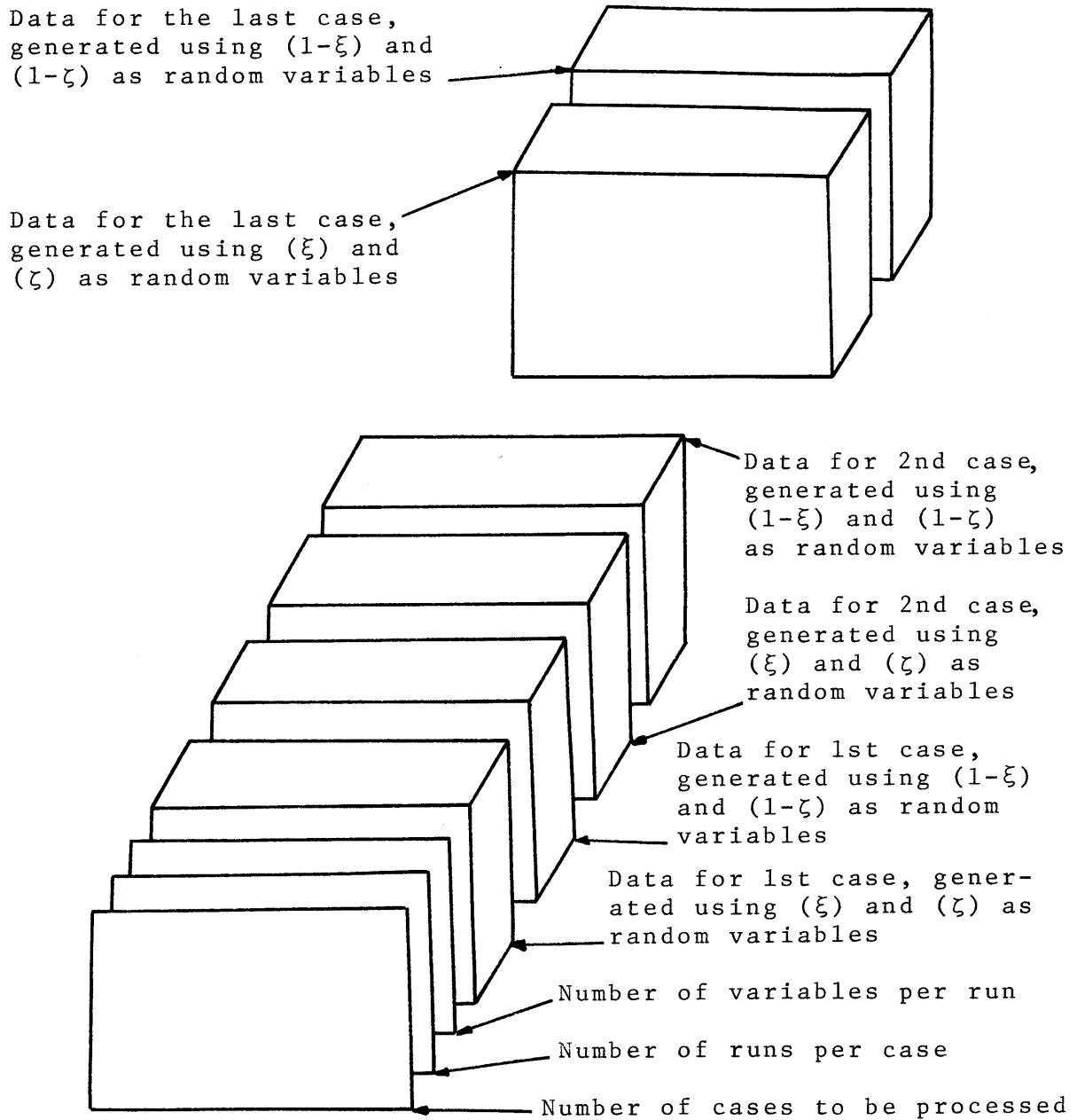


Fig. 6-18. Input Data Setup for STATIC

7. Evaluation of Results, Conclusions, and Future Recommendations.

192.

From the results shown in Section 6, it may be seen that the method of antithetic variance improves the efficiency of our methodology (i.e., $\eta > 1$), even when we must deal with complex mathematical models and serving strategies, such as the ones of our study. The relatively low values of η are in agreement with the observation made in Section 5 (in the guidelines to the user) to the effect that when a queue is formed in our system (as in this study), the expected value of η is low. An examination of the operational characteristics (see Appendix B) of the T.V. utilized in this study will confirm that a queue will be formed in our system. This is because the T.V. have similar characteristics, and so they will be arriving in groups in the waiting areas, which will cause a queue to form.

Cases 1, 2, 3 and 6 (see Table 6-1) were examined in order to determine the appropriate number and characteristics of the T.V. to be used in this study; these were so chosen as to yield a closure time for the Mother Ship of less than 12 hours (12 hours being the time in which similar systems unload the same type and number of cargo units). Of the cases examined, Case 6 was the only one to satisfy the above requirements. In Case 6, the number was the same, and the characteristics were similar to those used in general amphibious operations, which was to be expected, because our system, cargo and closure time are similar to those used in

these types of operations. This fact serves as a gross indicator that our mathematical model is correct.

Cases 4-10 (see Table 6-1) were examined in order to study the effect of the different use strategies upon closure time. First, it was observed that as the cargo stowage factor was between 60-80 ft.³/ton (i.e., our system was neither weight nor volume limited), the T.V. use strategies ASLTVA and BSLTVA, or ASLTVB and BSLTVB were expected to be equivalent. This was substantiated by the results of Cases 4-7 (see Tables 6.2-6.4).

Next, it was observed that because the number of payload units is small (270), then the expected number of round trips made by each T.V. will be such that no more than one refuelling will be required by each T.V. during the entire mission. For this reason, strategies ASLTVA and ASLTVB or ASLTVB and ASLTVB and BSLTVA and BSLTVB or BSLTVB and BSLTVB were expected to be equivalent. This was substantiated by the results of Case 8.

Finally, it was observed that when use strategies ASLTVE and SLSCC were used, it was expected that the closure time would obtain its minimum value, because these strategies endeavor to give the T.V. the best possible utility. In other words, the minimum number of round trips per T.V. is expected. This expectation was substantiated by the results of Tables 6.2-6.4. However, the user should observe that the variance associated with this case is high, which

somewhat reduces the attractiveness of this set of use strategies. This large variance is explained by the following argument. The SLSCC selects from among the free S.U.F. the one that will give the best utility to the T.V. available in W.A.I. Because of this, the selection becomes highly dependent upon the characteristics of the T.V., and ignores the number of containers remaining to be unloaded by the different S.U.F. In certain cases, this may result in there being only one crane to unload at the end of the mission. This situation will give rise to a high closure time in these cases, and hence to a high variance.

In order to substantiate this argument, Case 10 was examined. In this case, use strategies ASLTVE and SLSCB were employed (SLSCB selects S.U.F. in such a way that the numbers of payload units remaining to be unloaded by any S.U.F. at any instant are approximately equal). The variance associated with Case 10 was small, as was expected, and the closure time remained lower than that of the closure times found in Cases 4-8, but higher than that of Case 9.

Before leaving the subject of use strategies, it will be to the user's advantage to note the following reasons why a use strategy that allows a T.V. to visit more than one crane per trip is not attractive:

- 1) The structure of our model is such that it does not easily allow the introduction of this strategy, which would significantly add to computer effort, making the

model both inefficient and more difficult to use. 195.

- 2) It would make the unloading procedure difficult to implement in practice, which is contrary to the stipulation made when selecting Digital Simulation as the solution method (see Section 2).
- 3) The introduction of such a strategy is not expected to offer any saving in time, as the T.V. have a very high utility (see Sig. 7-1 where the % utility of our T.V. is shown for a typical trip).

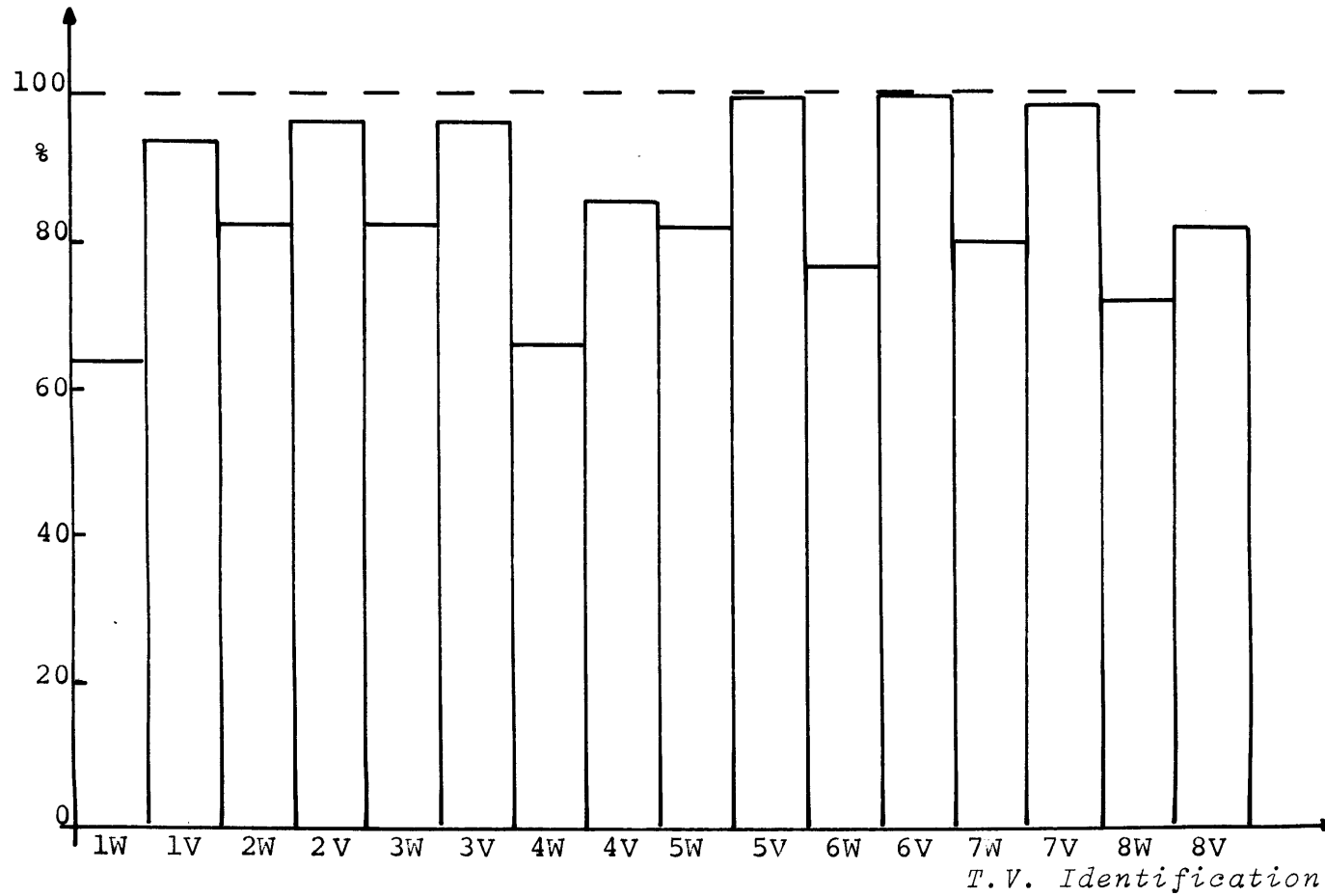
The above statements are corroborated by the fact that in common practice, to the author's knowledge, such a strategy is never used.

In conclusion, the following points are brought to the reader's attention:

The user is encouraged to employ the concept of antithetic variance in congestion problems because it is always profitable (see results of Sections 5 and 6).

The user is encouraged to utilize the suggested methodology for testing the merit of the use strategies he proposes to employ, even if they appear to be very efficient, because they might yield unexpected results (as was exemplified in the results of Case 9, where the variance associated with this case was unexpectedly high).

Although it is anticipated that for all cases likely to be encountered in practice, a set of good strategies may be



Weight (W) and Volume (V) Utility of Transfer Vehicles

Fig. 7-1

may be found among those incorporated into our model, the algorithm is sufficiently flexible to allow the introduction of more use strategies for the investigation of cases that were not predicted here.

Finally, an important by-product of this study is that the proposed methodology may be used as a designer's tool in the design of novel hardware (S.U.F., B.U.F. and especially T.V.). This is so because the model provides the results of the system's intermediate state, which in turn allows the designer to determine more correctly the best characteristics of such hardware.

Before concluding this report, the author wishes to take the opportunity to recommend areas of possible future research.

1. Graphic representation of the simulation as it is executed, because this will allow the user to gain a better insight into the operation and thus to select the correct use strategies with more confidence.

2. A continuation of the systematic analysis (as performed here) of the effect of antithetic variance upon the statistics of more complex congestion models, utilizing input distributions that are not necessarily restricted to uniform ones. This would be worthwhile because it would allow more specific user guidelines to be developed.

- Bellman, Richard Ernest. Dynamic Programming. Princeton, New Jersey: Princeton University Press, 1957.
- Blood, B. E., ed. A System Concept for HYSURCH (Hydrographic survey and charting system). Massachusetts Institute of Technology, Experimental Astronomy Laboratory, RE-39, 1968.
- Cramér, Harald. Mathematical Methods of Statistics. Princeton, New Jersey: Princeton University Press, 1946.
- Drake, Alvin W. Fundamentals of Applied Probability Theory. New York: McGraw-Hill, 1967.
- Dreyfus, Stuart E. Dynamic Programming and the Calculus of Variations. New York: Academic Press, 1965.
- Duffin, Richard James; Peterson, Elmor L.; and Zener, Clarence. Geometric Programming: Theory and Application. New York: Wiley, 1967.
- Feller, William. An Introduction to Probability Theory and Its Applications. 2nd ed. New York: Wiley, 1957.
- Fisher, Sir Ronald Aylmer. Statistical Methods for Research Workers. 13th ed., rev. New York: Hafner, 1958.
- Fisz, Marek. Probability Theory and Mathematical Statistics. Translated by R. Bartoszynski. 3rd ed. New York: Wiley, 1963.
- Fraser, Donald Alexander Stuart. Statistics, an Introduction. New York: Wiley, 1958.
- Freeman, Harold Adolph. Introduction to Statistical Inference. Reading, Mass.: Addison-Wesley, 1963.
- Geary, Robert Charles, and Pearson, Egon Sharpe. Tests of Normality. Cambridge, England: Cambridge University Press, 1938.
- Gloster, Lawrence R., and Heyrman, Jacques S. "Offshore Barge Transportation on the Pacific Coast." Transactions of the Society of Naval Architects and Marine Engineers, LXXIII(1965), 497-533.
- Groninger, Kent L. "A Scheduling Algorithm for Deployment Planning." Unpublished Civil Engineers degree dissertation, Massachusetts Institute of Technology, Department of Civil Engineering, 1968.

- Hammersley, J. M., and Mauldon, J. G., "General Principles of Antithetic Variates." Proceedings of the Cambridge Philosophical Society, LII (July, 1956), 476-81.
- _____, and Handscomb, D. C. Monte Carlo Methods. Rev. ed. New York: Wiley, 1965.
- _____, and Morton, K. W. "A New Monte Carlo Technique: Antithetic Variates." Proceedings of the Cambridge Philosophical Society, LII (July, 1956), 449-75.
- Hardy, G. H.,; Littlewood, J. E.; and Polya, G. Inequalities. 2nd ed. Cambridge, England: Cambridge University Press, 1952.
- Harling, John. "Simulation Techniques in Operations Research--a Review." Operations Research, VI (May-June, 1958), 307-319.
- Henry, J. J. Co., Inc. Lykes Sea Barge Clipper. (Plans).
- Howard, Ronald A. Dynamic Programming and Markov Processes. Cambridge, Mass.: M.I.T. Technology Press, 1960.
- Hull, T. E. and Dobell, A. R. "Random Number Generators." SIAM Review, IV (July, 1962), 230-54.
- International Business Machines Corporation. System/360 Scientific Subroutine Package (360A-CM-03X) Version III, Programmers Manual. H20-0205-3. 4th ed. IBM, 1968.
- Mandel, Philip. Unpublished letter to E. G. Frankel, Litton Industries, Washington, D. C., October 18, 1966. (Typewritten).
- Mode, Elmer B. Elements of Statistics. 3rd ed. Englewood Cliffs, New Jersey: Prentice-Hall, 1961.
- Mood, Alexander McFarlane, and Graybill, A. Introduction to the Theory of Statistics. 2nd ed. New York: McGraw-Hill, 1963.
- Morton, K. W. Criticality Calculations by Monte Carlo Methods. Great Britain, Atomic Energy Research Establishment. AERE-T/R-1903, March, 1956.
- National Research Council. Maritime Cargo Transportation Conference: San Francisco Port Study. National Research Council Publication 1140A-B. Washington: National Academy of Science - National Research Council, 1964-.

Naval Ship Engineering Center (NAVSEC). Boats of the United States Navy. Washington, D. C., U. S. Department of the Navy, Naval Ship Systems Command, NAVSHIPS 250-452, 1968?

Naylor, Thomas H., et al. Computer Simulation Techniques. New York: Wiley, 1966.

Novaes, A., and Frankel, E. "A Queuing Model for Unitized Cargo Generation." Operations Research, XIV (January-February, 1966), 100-32.

Page, E. S. "On Monte Carlo Methods in Congestion Problems: II. Simulation of Queuing Systems." Operations Research, XIII (March-April, 1965), 300-5.

Panitz, George. "Helicopter Shows Cargo Lift Ability." Journal of Commerce, January 30, 1967, p. 23.

Savage, Leonard H. Foundations of Statistics. New York: Wiley, 1954.

Shreider, Iulii Anatolevich, ed. The Monte Carlo Method; the Method of Statistical Trials. Translated by G. J. Tee. New York: Pergamon, 1966.

Stevens, C. C. Amphibious Assault Landing Craft Handling Systems Concepts. U.S. Naval Ship Research and Development Center. Research and Development Report 2700, AD837823. August, 1968.

Symposium on Monte Carlo Methods, University of Florida, 1964. Papers. Edited by Herbert A. Meyer. New York: Wiley, 1956.

Tocher, K. D. The Art of Simulation. London: English Universities Press, 1963.

Wall Street Journal. "Two Concerns Offer Savings of \$33,864,480 on Freight to Vietnam." May 4, 1966, p. 13.

Wilde, Douglass J., and Beightler, Charles S. Foundations of Optimization. Englewood Cliffs, New Jersey: Prentice-Hall, 1967.

Williams, Ira E., and Wischhoefer, William J. G. "New Look for Future LST's." Naval Engineers Journal, LXXVIII (October, 1966), 815-24.

ADDITIONAL INFORMATION PERTAINING TO THE SOLUTION METHOD1. Transformation of Probability Density Functions (P.D.F.)

We wish to find the relationship between the p.d.f. $P_{\xi}(x)$ of random variable ξ and the p.d.f. $P_{\zeta}(y)$ of random variable ζ when the values of ξ and ζ are related by

$$\zeta = f(\xi) \quad (\text{A-1})$$

such that ξ and ζ have a one to one correspondence.

The required relationship is given by

$$P_{\zeta}(y) = P_{\xi}(x) \left| \frac{d\xi}{d\zeta} \right| = P_{\xi}(x) \left| \frac{1}{f'(x)} \right| \quad (\text{A-2})$$

Proof.

Because every point in the range of ξ has one and only one corresponding point in the range of ζ we can state that

$$\overline{P}(x < \xi < x + \delta\xi) = \overline{P}(y < \zeta < y + \delta\zeta)$$

where \overline{P} is the probability.

Then it follows that

$$P_{\xi}(x)d\xi = P_{\zeta}(y)d\zeta \quad (\text{A-3})$$

and as $P_{\xi}(x)$ and $P_{\zeta}(y) > 0$,

then it follows from equation (A-3)

$$P_{\zeta}(y) = P_{\xi}(x) \left| \frac{d\xi}{d\zeta} \right|$$

and using equation (A-1)

$$P_{\zeta}(y) = P_{\xi}(x) \left| \frac{1}{f'(x)} \right|$$

Q.E.D.

2. Transformation of a $U(0,1)$ Random Variable to a Random Variable of a Given p.d.f.

Given a $U(0,1)$ random variable with p.d.f. $P_{\xi}(x)$ such that

$$\begin{aligned} P_{\xi}(x) &= 1 & 0 < x < 1 \\ &= 0 & \text{otherwise} \end{aligned} \quad (\text{A-4})$$

we wish to transform ξ into a new ζ such that

$$\zeta = f(\xi) \quad (\text{A-5})$$

so that the values of ξ and ζ have a one to one correspondence and the p.d.f. of ζ is a given function $P_{\zeta}(y)$.

The required relationship is given by

$$\zeta = Q_{\zeta}^{-1}(\xi) \quad 0 < \xi < 1 \quad (\text{A-6})$$

where Q_{ζ}^{-1} is the inverse of Q_{ζ} of the following expression

$$\xi = Q_{\zeta}(y) \quad 0 < \xi < 1 \quad (\text{A-7})$$

and

$$\begin{aligned} Q_{\zeta}(y) &= \text{cumulative distribution function} \\ &= \int_{-\infty}^y P_{\zeta}(y) dy \end{aligned}$$

Proof.

Because

$$Q_{\zeta}(y) = \int_{-\infty}^y P_{\zeta}(y) dy$$

then

$$\begin{aligned} Q'_{\zeta}(y) &= \frac{d}{dy} \int_{-\infty}^y P_{\zeta}(y) dy \\ &= P_{\zeta}(y) \end{aligned} \quad (\text{A-7a})$$

From equations (A-7) and (A-7a) it follows that

203.

$$\frac{d\xi}{d\zeta} = Q'_\zeta(y) = P_\zeta(y) \quad 0 < \xi < 1$$

Then from equation (A-2)

$$P_\zeta(y) = P_\xi(x) |P_\zeta(y)| \quad 0 < \xi < 1$$

but as $P_\zeta(y) > 0$

it follows that

$$P_\xi(x) = 1 \quad 0 < \xi < 1$$

as assumed.

It is of interest to note that although in theory we can assume that the inverse functional relationship (Q_ζ^{-1}) of equation (A-7) always exists, in practice quite frequently such inversion is impossible. In such situations, other techniques exist to achieve the desired goal, and for these the reader is referred to any of the standard digital simulation text books. However, as all the techniques in existence are based upon manipulations of $U(0,1)$ random variables, the fact that equation (A-6) is not always obtainable in practice imposes no restrictions upon our discussion, as it may be substituted by the functional relationship implied by the above mentioned techniques.

3. Proof that the Transformations given by Equations (5.42) and (5.43) Lead to Negatively Correlated d' and d'' .

Although we will present the mathematical proof that the transformations given by equations (5.42) and (5.43) indeed lead to negatively correlated d' and d'' , a better physical insight into our methodology is gained if we first present the following heuristic proof.

i) Heuristic Proof.

If in our system we obtain a sequence of small x 's and large y 's, i.e., a period of rapid arrivals of customers needing much service, this will cause a queue to be formed. Conversely, a sequence of large x 's and small y 's, i.e., a period of slow arrivals of customers needing little service, will cause a queue dispersion. Periods containing such sequences (arising in the course of independent sampling) will each give unbiased estimates of the expected waiting time of a customer. However, if we arrange the periods so that for each busy period we obtain a slack period, and conversely, then the combination of two such periods is likely to yield a sequence of samples which will estimate the expected waiting time of a customer with smaller variance than we would have obtained had we used the same number of samples gathered by independent sampling, with the same number of observations. Our proposed transformations are striving to achieve the above mentioned matching of slack periods with busy, and conversely. This is because a large interarrival time (ξ') and a small service time (ζ') in one sequence correspond to a small

interarrival time $(1-\xi')$ and a large service time $(1-\zeta')$ in the dependent sequence, and conversely. It is likely, therefore, that the variance of d (and hence w 's) when calculated using such dependent samples will be smaller than if we used the same number of independent samples obtained from the same number of observations. Now using equations (5.10) and (5.11) the condition for smaller variance is that $cov(d', d'')$ in the dependent sampling should be negative as required.

ii) Mathematical Proof.

Here we wish to verify that

$$cov(d', d'') \leq 0 \quad (\text{A-8})$$

Using equation (5.35), the above equation may be rewritten as follows.

$$E\left[\phi(\xi')\phi(\xi'')\right] + E\left[\psi(\zeta')\psi(\zeta'')\right] - \mu_{\zeta}^2 - \mu_{\xi}^2 \leq 0 \quad (\text{A-9})$$

Now we observe that if

$$E[\phi(\xi')\phi(\xi'')] - \mu_{\zeta}^2 \leq 0 \quad (\text{A-10})$$

and

$$E[\psi(\zeta')\psi(\zeta'')] - \mu_{\xi}^2 \leq 0 \quad (\text{A-11})$$

then equation (A-9) is automatically satisfied. So we may proceed with our proof by considering equations (A-10) and (A-11) rather than equation (A-9)

Now using the fact that ξ' , ζ' , ξ'' and ζ'' are random numbers drawn from a $U(0,1)$ distribution, and using equations (5.42) and (5.43), then equations (A-10) and (A-11) may be rewritten as follows.

$$\int_0^1 \phi(\xi') \phi(1-\xi') d\xi' - \mu_i^2 \leq 0 \quad (\text{A-12})$$

$$\int_0^1 \psi(\zeta') \psi(1-\zeta') d\zeta' - \mu_s^2 \leq 0 \quad (\text{A-13})$$

From the definition of our system it follows that

$$\mu_i = \int_0^1 \phi(\xi') d\xi' = \int_0^1 \phi(1-\xi') d\xi'$$

and

$$\mu_s = \int_0^1 \psi(\zeta') d\zeta' = \int_0^1 \psi(1-\zeta') d\zeta'$$

so equations (A-12) and (A-13) may be rewritten as follows.

$$\int_0^1 \phi(\xi') \phi(1-\xi') d\xi' \leq \int_0^1 \phi(\xi') d\xi' \int_0^1 \phi(1-\xi') d\xi' \quad (\text{A-14})$$

$$\int_0^1 \psi(\zeta') \psi(1-\zeta') d\zeta' \leq \int_0^1 \psi(\zeta') d\zeta' \int_0^1 \psi(1-\zeta') d\zeta' \quad (\text{A-15})$$

To prove that equations (A-14) and (A-15) are true, we may proceed as follows. Define

$$I = \int_0^1 [f(x) - \bar{f}] g(x) dx = \int_0^1 f(x) g(x) dx - \int_0^1 \bar{f} g(x) dx \quad (\text{A-16})$$

where $f(x) \geq 0$, continuous, and monotonically increasing in $0 \leq x \leq 1$

$$\bar{f} = \int_0^1 f(x) dx$$

and $g(x) \geq 0$, continuous, and monotonically decreasing in $0 \leq x \leq 1$.

Now as $\bar{f} = \int_0^1 f(x) dx =$ a constant for a given $f(x)$, equation (A-16) may be rewritten as follows.

$$I = \int_0^1 f(x) g(x) dx - \int_0^1 f(x) dx \int_0^1 g(x) dx \quad (\text{A-17})$$

and because of the definition of $f(x)$ there exists an X in

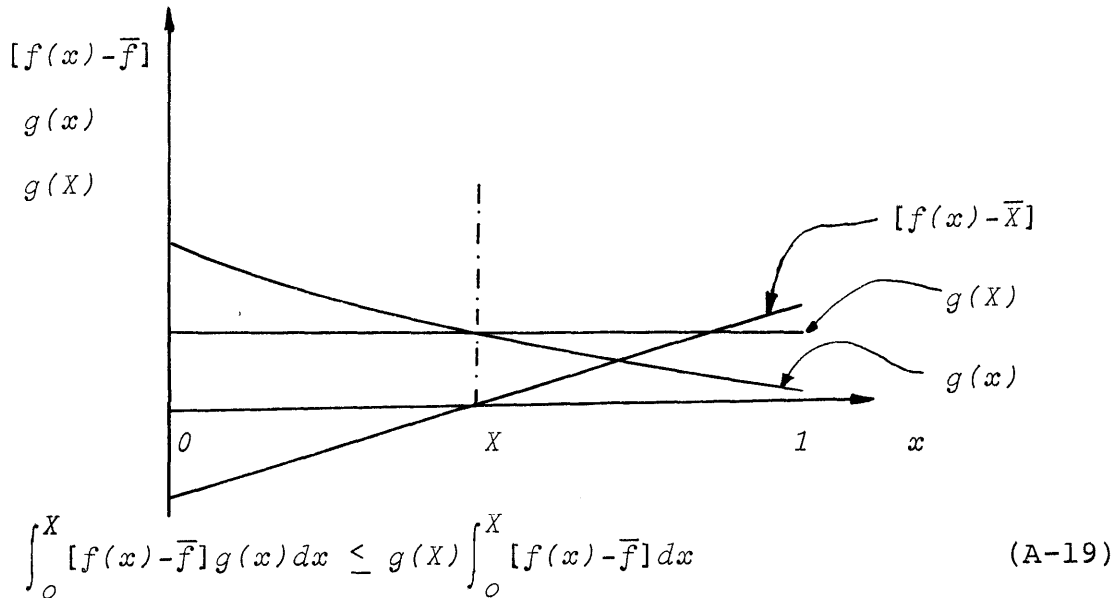
the range $0,1$ such that

$$f(X) = \int_0^1 f(x) dx$$

then equation (A-16) may also be rewritten as follows.

$$I = \int_0^X [f(x) - \bar{f}] g(x) dx + \int_X^1 [f(x) - \bar{f}] g(x) dx \quad (\text{A-18})$$

Now if we plot $[f(x) - \bar{f}]$, $g(x)$, $g(X)$, versus x we observe that



because

$$[f(x) - \bar{f}] \leq 0 \text{ and } g(x) \geq g(X) \text{ in } 0 \leq x \leq X,$$

and that

$$\int_X^1 [f(x) - \bar{f}] g(x) dx \leq g(X) \int_X^1 [f(x) - \bar{f}] dx \quad (\text{A-20})$$

because

$$[f(x) - \bar{f}] \geq 0 \text{ and } g(x) \leq g(X) \text{ in } X \leq x \leq 1.$$

Substituting (A-19) and (A-20) in (A-18) it follows that

$$I \leq g(X) \int_0^X [f(x) - \bar{f}] dx + g(X) \int_X^1 [f(x) - \bar{f}] dx$$

or
$$I \leq g(X) \int_0^1 [f(x) - \bar{f}] dx$$

or
$$I \leq 0$$
 as
$$\int_0^1 [f(x) - \bar{f}] dx = 0$$
 because of the definition of \bar{f}

It follows, then, from equation (A-17) that

$$\int_0^1 f(x)g(x) dx \leq \int_0^1 f(x) dx \int_0^1 g(x) dx \quad (\text{A-21})$$

and as $f(x)$ and $g(x)$ have the same characteristics as $\phi(\xi')$ and $\phi(1-\xi')$ and $\psi(\zeta')$ and $\psi(1-\zeta')$, then equations (A-14) and (A-15) are true because they are identical in nature to equation (A-21). In other words, because equations (A-14) and (A-15) are true, it follows that equation (A-8) is also true, as required.

4. Proof that the Transformations given by (5.50) and (5.51) lead to Negatively Correlated d' and d'' .

As with the previous transformations, it is to our advantage to start with a heuristic proof, because such a proof offers a physical insight into our methodology, and to then present a rigorous mathematical proof that the transformation given by equations (5.50) and (5.51) indeed yield negatively correlated d' and d'' .

i) Heuristic Proof.

As in the previous case (see Appendix A part 3), if we arrange the sampling periods so that for each busy period we obtain a slack period, and conversely, then the combination of two such periods is likely to yield a sequence of samples that will estimate the expected waiting time of a customer with smaller variance than we would have obtained had we used the same number of samples gathered by independent sampling, with the same number of observations.

Our proposed transformations are striving to achieve the above mentioned matching of slack periods with busy, and conversely. This is because a large interarrival time (ξ') and a small service time (ζ') in one sequence correspond to a small interarrival time (ζ') and a large service time (ξ') in the dependent sequence, and conversely. It is likely, therefore, that the variance of \bar{d} (and hence w 's) when calculated using such dependent samples will be smaller than if we used the same number of independent samples obtained from the same number of observations. Now using equations (5.10) and (5.11), the condition for smaller variance is that $cov(\bar{d}', \bar{d}'')$ in the dependent sampling should be negative as required.

ii) Mathematical Proof.

Here we wish to verify that

$$cov(\bar{d}', \bar{d}'') \leq 0 \quad (A-22)$$

Using equation (5.45) the above equation may be rewritten as follows.

$$2\mu_i\mu_s - E\left[\phi(\xi')\psi(\zeta'')\right] - E\left[\phi(\xi'')\psi(\zeta')\right] \leq 0 \quad (\text{A-23})$$

Now we observe that if

$$\mu_i\mu_s - E\left[\phi(\xi')\psi(\zeta'')\right] \leq 0 \quad (\text{A-24})$$

and

$$\mu_i\mu_s - E\left[\phi(\xi'')\psi(\zeta')\right] \leq 0 \quad (\text{A-25})$$

then equation (A-23) is automatically satisfied and so we may proceed with our proof by considering equations (A-24) and (A-25) rather than equation (A-23).

Now using the fact that ξ' , ζ' , ξ'' and ζ'' are random numbers drawn from a $U(0,1)$ distribution, and using equations (5.50) and (5.51), then equations (A-24) and (A-25) may be rewritten as follows.

$$\mu_i\mu_s - \int_0^1 \phi(\xi')\psi(\xi')d\xi' \leq 0 \quad (\text{A-26})$$

$$\mu_i\mu_s - \int_0^1 \phi(\zeta')\psi(\zeta')d\zeta' \leq 0 \quad (\text{A-27})$$

From the definition of our system it follows that

$$\mu_i = \int_0^1 \phi(\xi')d\xi' = \int_0^1 \phi(\zeta')d\zeta'$$

and

$$\mu_s = \int_0^1 \psi(\zeta')d\zeta' = \int_0^1 \psi(\xi')d\xi'$$

so equation (A-26) and (A-27) may be written as follows.

$$\int_0^1 \phi(\xi')d\xi' \int_0^1 \psi(\xi')d\xi' \leq \int_0^1 \phi(\xi')\psi(\xi')d\xi' \quad (\text{A-28})$$

$$\int_0^1 \phi(\zeta')d\zeta' \int_0^1 \psi(\zeta')d\zeta' \leq \int_0^1 \phi(\zeta')\psi(\zeta')d\zeta' \quad (\text{A-29})$$

To prove that equations (A-28) and (A-29) are true we may 211.
 proceed as follows. Define

$$I = \int_0^1 [f(x) - \bar{f}] g(x) dx = \int_0^1 f(x) g(x) dx - \int_0^1 \bar{f} g(x) dx \quad (\text{A-30})$$

where $f(x) \geq 0$ continuous and monotonically increasing in $0 \leq x \leq 1$

$$\bar{f} = \int_0^1 f(x) dx$$

and $g(x) \geq 0$ continuous and monotonically increasing in $0 \leq x \leq 1$.

Now as $\bar{f} = \int_0^1 f(x) dx =$ a constant for a given $f(x)$, equation

(A-30) may be rewritten as follows:

$$I = \int_0^1 f(x) g(x) dx - \int_0^1 f(x) dx \int_0^1 g(x) dx \quad (\text{A-31})$$

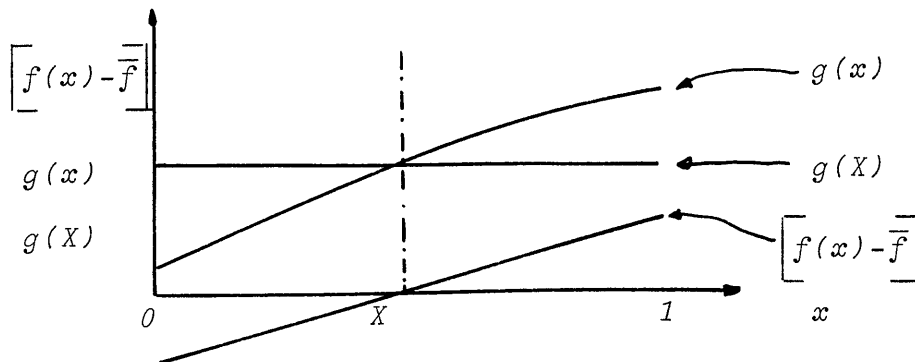
and because of the definition of $f(x)$ there exists an X in the range $0, 1$ such that

$$f(X) = \int_0^1 f(x) dx$$

then equation (A-16) may also be rewritten as follows

$$I = \int_0^X [f(x) - \bar{f}] g(x) dx + \int_X^1 [f(x) - \bar{f}] g(x) dx \quad (\text{A-32})$$

Now if we plot $[f(x) - \bar{f}]$, $g(x)$, $g(X)$ versus x we observe that



$$\int_0^X [f(x) - \bar{f}] g(x) dx \geq g(X) \int_0^X [f(x) - \bar{f}] dx \quad (\text{A-33})$$

because $[f(x) - \bar{f}] \leq 0$ and $g(x) \leq g(X)$ in $0 \leq x \leq X$

and that

$$\int_X^1 [f(x) - \bar{f}] g(x) dx \geq g(X) \int_X^1 [f(x) - \bar{f}] dx \quad (\text{A-34})$$

because $[f(x) - \bar{f}] \geq 0$ and $g(x) \geq g(X)$ in $X \leq x \leq 1$.

Substituting (A-33) and (A-34) in (A-32), it follows that

$$I \geq g(X) \int_0^X [f(x) - \bar{f}] dx + g(X) \int_X^1 [f(x) - \bar{f}] dx$$

$$\text{or } I \geq g(X) \int_0^1 [f(x) - \bar{f}] dx$$

$$\text{or } I \geq 0 \text{ as } \int_0^1 [f(x) - \bar{f}] dx = 0 \text{ because of the definition of } \bar{f}$$

It follows then from equation (A-31)

$$\int_0^1 f(x) g(x) dx \geq \int_0^1 f(x) dx \int_0^1 g(x) dx$$

$$\text{or } \int_0^1 f(x) dx \int_0^1 g(x) dx \leq \int_0^1 f(x) g(x) dx \quad (\text{A-35})$$

and as $f(x)$ and $g(x)$ have the same characteristics as $\phi(\xi')$ and $\psi(\xi')$ and $\phi(\zeta')$ and $\psi(\zeta')$, then equations (A-28) and (A-29) are true because they are identical in nature to equation (A-35). In other words, because equations (A-28) and (A-29) are true, it follows that equation (A-22) is also true, as required.

5. Uniform Probability Density Function.

213.

The uniform p.d.f. is given by

$$\begin{aligned}
 f_x(x_0) &= \frac{1}{b-a} & a < x_0 < b \\
 &= 0 & \text{otherwise} \\
 & & -\infty < a < b < \infty
 \end{aligned}$$

The expected value of such distribution is given by

$$E(x) = \mu_x = \frac{a+b}{2} \quad (\text{A-36})$$

and the variance by

$$E\left[(x-\mu_x)^2\right] = \sigma_x^2 = \frac{(b-a)^2}{12} \quad (\text{A-37})$$

To compute the values of a and b to yield a given μ_x and σ_x^2 the following equations may be used.

$$a = \mu_x - \sqrt{3\sigma_x^2} \quad (\text{A-38})$$

$$b = \mu_x + \sqrt{3\sigma_x^2} \quad (\text{A-39})$$

6. Input Data for the Experiment Leading to Figs. 5-3 and 5-4

<u>Case No.</u>	<u>Seed for the Customer Interarrival p.d.f.</u>	<u>Seed for the Customer Service p.d.f.</u>
1	65539	65533
2	630196675	250300163
3	845580931	913814595
4	319852035	751391107
5	350305091	728814851
6	213263811	197123971
7	350380803	777234051
8	16764995	603171331
9	659904323	757456451

APPENDIX B

Input Data Listing

In this Appendix, the Input Data for Test Case No. 10 of Table 6-1 is listed. In order to obtain the correct Input Data for Cases 4-9, the magnitude of *ISUD*, *IBUD*, *IWA1SL*, *IWA2SL*, *ISCSL* *IBCSL* and *ICHANG* (which is the card before the last) must be modified to the values shown in Table 6-1.

In order to obtain the correct Input Data for Cases 1-3 (apart from the above correction), the user must remove the Input Data pertaining to the appropriate T.V. For guidance, the user is referred to Figs. 6-4, 6-8, 6-12, 6-16 and 6-17, and Table 6-1.

1													DATA	1
1	8	4	4										DATA	2
80	80	60	50										DATA	3
7.50	72	7.40	72	7.50	72	7.40	72	7.50	72	7.35	72	DATA	4	5
7.12	72	7.34	72	7.12	72	7.35	72	9.00	99	8.80	99	DATA	6	6
8.50	99	8.80	99	9.00	99	8.90	99	8.28	99	8.30	99	DATA	7	7
8.28	99	8.90	99	7.00	72	7.10	72	6.80	72	7.10	72	DATA	8	8
7.00	72	7.13	72	7.43	72	7.25	72	7.43	72	7.13	72	DATA	9	9
8.20	99	8.35	99	8.40	99	8.35	99	8.20	99	8.00	99	DATA	10	10
8.14	99	8.50	99	8.14	99	8.00	99	6.00	72	6.35	72	DATA	11	11
6.50	72	6.35	72	6.00	72	5.85	72	5.60	72	5.50	72	DATA	12	12
5.60	72	5.85	72	7.00	99	7.19	99	7.50	99	7.19	99	DATA	13	13
7.00	99	6.85	99	7.25	99	7.50	99	7.25	99	6.85	99	DATA	14	14
4.50	72	5.00	72	5.25	72	5.00	72	4.50	72	4.75	72	DATA	15	15
4.85	72	5.13	72	4.85	72	4.75	72	6.00	99	6.32	99	DATA	16	16
6.51	99	6.32	99	6.00	99	6.13	99	6.19	99	6.39	99	DATA	17	17
6.19	99	6.13	99	7.32	72	7.42	72	7.50	72	7.42	72	DATA	18	18
7.32	72	7.00	72	7.10	72	7.46	72	7.10	72	7.00	72	DATA	19	19
6.80	72	7.30	72	7.50	72	7.30	72	6.80	72	8.50	99	DATA	20	20
8.80	99	9.00	99	8.80	99	8.50	99	6.50	72	6.82	72	DATA	21	21
7.12	72	6.82	72	6.50	72	6.72	72	7.00	72	7.10	72	DATA	22	22
7.00	72	6.72	72	6.80	72	6.90	72	7.00	72	6.90	72	DATA	23	23
6.80	72	7.00	99	7.50	99	8.00	99	7.50	99	7.00	99	DATA	24	24
4.50	72	4.75	72	4.95	72	4.75	72	4.50	72	4.63	72	DATA	25	25
5.00	72	5.22	72	5.00	72	4.63	72	4.90	72	5.30	72	DATA	26	26
5.80	72	5.30	72	4.90	72	6.60	99	7.00	99	7.20	99	DATA	27	27
7.00	99	6.60	99	4.50	72	4.68	72	4.93	72	4.68	72	DATA	28	28
4.50	72	4.50	72	4.85	72	5.00	72	4.85	72	4.50	72	DATA	29	29
4.62	72	5.19	72	5.50	72	5.19	72	4.62	72	6.00	99	DATA	30	30
6.50	99	7.00	99	6.50	99	6.00	99	7.32	72	7.42	72	DATA	31	31
7.50	72	7.42	72	7.32	72	7.00	72	7.13	72	7.50	72	DATA	32	32
7.13	72	7.00	72	8.00	99	8.50	99	8.89	99	8.50	99	DATA	33	33
8.00	99	6.00	72	6.10	72	6.23	72	6.10	72	6.00	72	DATA	34	34
6.05	72	6.19	72	6.38	72	6.19	72	6.05	72	7.00	99	DATA	35	35
7.33	99	7.77	99	7.33	99	7.00	99	5.82	72	5.89	72	DATA	36	36

5.90	72	5.89	72	5.82	72	5.00	72	5.20	72	5.69	72	DATA	37
5.20	72	5.00	72	6.69	99	7.00	99	7.33	99	7.00	99	DATA	38
6.69	99	4.50	72	4.69	72	4.99	72	4.69	72	4.50	72	DATA	39
4.51	72	4.53	72	4.55	72	4.53	72	4.51	72	6.00	99	DATA	40
6.10	99	6.20	99	6.10	99	6.00	99	10.00	112	10.00	112	DATA	41
9.85	112	10.00	112	10.00	112	9.80	112	9.00	112	9.25	112	DATA	42
9.00	112	9.80	112	9.80	112	9.70	112	9.00	112	9.70	112	DATA	43
9.80	112	9.00	112	8.50	112	8.70	112	8.50	112	9.00	112	DATA	44
8.00	112	7.50	112	7.80	112	7.50	112	8.00	112	8.00	112	DATA	45
8.20	112	8.30	112	8.20	112	8.00	112	7.95	112	7.50	112	DATA	46
7.80	112	7.50	112	7.95	112	7.35	112	7.00	112	7.40	112	DATA	47
7.00	112	7.35	112	7.40	112	7.25	112	7.00	112	7.25	112	DATA	48
7.40	112	7.00	112	7.05	112	7.00	112	7.05	112	7.00	112	DATA	49
26.8	289	30.4	412.5	30.4	412.5	53.6	660	58	717.5	58	717.5	DATA	50
53.6	660	30.4	412.5									DATA	51
0	20	15										DATA	52
1	1	1.5	5									DATA	53
0.400	.400	.500	.50									DATA	54
0.200	.200	.200	.20									DATA	55
0.600	.651	.001	.00									DATA	56
0.350	.350	.350	.25									DATA	57
0.200	.200	.200	.40									DATA	58
0.500	.500	.752	.50									DATA	59
0.500	.500	.752	.50									DATA	60
-25	-25	-20	-10									DATA	61
5	1	15	10									DATA	62
0.500	.500	.500	.50									DATA	63
0.500	.300	.300	.50									DATA	64
0.500	.500	.500	.50									DATA	65
0.250	.250	.250	.25									DATA	66
1.501	.001	.001	.50									DATA	67
0.500	.500	.500	.50									DATA	68
10	10	10	10									DATA	69
-35	-35	-35	-35	-35	-35	-35	-35					DATA	70
35	38	38	39	37	37	39	38					DATA	71
0.901	.101	.101	.301	.301	.301	.301	.10					DATA	72

3.003.003.256.505.505.506.503.25
 70 74 74 74 72 72 74 74
 820 870 8701267 978 9781267 870
 2.002.102.102.202.202.202.202.10
 0.600.800.800.900.900.900.900.80
 32 35 35 35 34 34 35 35
 2.002.202.202.502.402.402.502.20
 2.003.003.004.004.004.004.003.00
 31 34 34 34 33 33 34 34
 35 38 38 39 37 37 39 38
 1 2 2
 1 1 1 1
 2 2 2 1
 2 2 2 1
 2 2 2 1
 1 1 1 1
 2 2 2 2
 1 1 1 1
 1 1 1 1
 2 2 2 1
 1 2 2 2
 1 1 1 1
 2 2 2 2
 2 2 2 2
 2 2 2 2
 2 2 2 2
 1 1 1 1
 1 1 1 1
 1 1 1 1 1 1 1 1
 2 2 2 2 2 2 2 2
 1 1 1 1 1 1 1 1
 2 2 2 2 2 2 2 2
 2 2 2 2 2 2 2 2
 2 2 2 2 2 2 2 2
 1 1 1 1 1 1 1 1
 2 2 2 2 2 2 2 2

DATA 73
 DATA 74
 DATA 75
 DATA 76
 DATA 77
 DATA 78
 DATA 79
 DATA 80
 DATA 81
 DATA 82
 DATA 83
 DATA 84
 DATA 85
 DATA 86
 DATA 87
 DATA 88
 DATA 89
 DATA 90
 DATA 91
 DATA 92
 DATA 93
 DATA 94
 DATA 95
 DATA 96
 DATA 97
 DATA 98
 DATA 99
 DATA 100
 DATA 101
 DATA 102
 DATA 103
 DATA 104
 DATA 105
 DATA 106
 DATA 107
 DATA 108

1	1	1	1	1	1	1	1
2	2	2	2	2	2	2	2
1	1	1	1	1	1	1	1
2	2	2	2	2	2	2	2
2	2	2	2	2	2	2	2
65539	10.0			30.0			
630196675	10.0			20.0			
250300163	0.25			0.55			
845580931	0.25			0.55			
913814595	0.25			0.75			
319852035	0.10			0.30			
751391107	0.10			0.30			
350305091	0.10			0.30			
728814851	0.50			0.70			
213263811	0.50			0.80			
197123971	0.50			1.50			
350380803	0.10			0.30			
777234051	0.10			0.30			
16764995	0.10			0.30			
603171331	0.20			0.60			
659904323	-30.0			-20.0			
757456451	-35.0			-15.0			
298268675	-22.0			-18.0			
327958979	0.0			2.0			
780762883	10.0			20.0			
904970883	0.0			20.0			
948356611	0.25			0.75			
841714051	0.20			0.40			
830042947	0.20			0.40			
271733763	0.25			0.75			
467704579	0.25			0.75			
522675395	0.25			0.75			
155049603	0.25			0.75			
281666051	0.25			0.75			
758606787	0.15			0.35			
778347907	0.15			0.35			

DATA	109
DATA	110
DATA	111
DATA	112
DATA	113
DATA	114
DATA	115
DATA	116
DATA	117
DATA	118
DATA	119
DATA	120
DATA	121
DATA	122
DATA	123
DATA	124
DATA	125
DATA	126
DATA	127
DATA	128
DATA	129
DATA	130
DATA	131
DATA	132
DATA	133
DATA	134
DATA	135
DATA	136
DATA	137
DATA	138
DATA	139
DATA	140
DATA	141
DATA	142
DATA	143
DATA	144

233711875	0.15	0.35
54686403	0.15	0.35
189164675	1.0	2.0
843935747	0.8	1.2
4749763	0.8	1.2
484947715	1.0	2.0
55148739	33.0	37.0
246948931	37.0	39.0
642630019	37.0	39.0
751938371	37.0	41.0
389844675	35.0	39.0
847021699	35.0	39.0
982134915	37.0	41.0
649681347	37.0	39.0
404457603	0.8	1.0
510014019	1.0	1.2
941132803	1.0	1.2
924556483	1.1	1.5
317200003	1.1	1.5
801933827	1.1	1.5
139146243	1.1	1.5
875303811	1.0	1.2
207624707	2.75	3.25
503695171	2.75	3.25
660365571	3.0	3.5
327568963	6.0	7.0
370502531	5.0	6.0
263599939	5.0	6.0
587414979	6.0	7.0
82041475	3.0	3.5
931255619	1.8	2.2
800273923	1.9	2.3
154139011	1.9	2.3
115991363	2.0	2.4
26967299	2.0	2.4
280615811	2.0	2.4

DATA	145
DATA	146
DATA	147
DATA	148
DATA	149
DATA	150
DATA	151
DATA	152
DATA	153
DATA	154
DATA	155
DATA	156
DATA	157
DATA	158
DATA	159
DATA	160
DATA	161
DATA	162
DATA	163
DATA	164
DATA	165
DATA	166
DATA	167
DATA	168
DATA	169
DATA	170
DATA	171
DATA	172
DATA	173
DATA	174
DATA	175
DATA	176
DATA	177
DATA	178
DATA	179
DATA	180

345700227	2.0	2.4
809043011	1.9	2.3
239126211	31.0	33.0
724993923	34.0	36.0
71168323	34.0	36.0
371002115	34.0	36.0
231724227	33.0	35.0
629549251	33.0	35.0
604922179	34.0	36.0
478553347	34.0	36.0
564164675	1.5	2.5
381047299	1.7	2.7
596630467	1.7	2.7
662568771	2.0	3.0
260741379	1.9	2.9
395944579	1.9	2.9
350768067	2.0	3.0
595880067	1.7	2.7
530178051	30.0	32.0
816967875	33.0	35.0
23686659	33.0	35.0
287945987	33.0	35.0
5240963	32.0	34.0
456419715	32.0	34.0
959401091	33.0	35.0
514265667	33.0	35.0
874839043	33.0	37.0
984024515	37.0	39.0
616966467	37.0	39.0
156975875	37.0	41.0
591662275	35.0	39.0
948516547	35.0	39.0
330757699	37.0	41.0
795684739	37.0	39.0
100.0	50.0	

1

DATA 181
 DATA 182
 DATA 183
 DATA 184
 DATA 185
 DATA 186
 DATA 187
 DATA 188
 DATA 189
 DATA 190
 DATA 191
 DATA 192
 DATA 193
 DATA 194
 DATA 195
 DATA 196
 DATA 197
 DATA 198
 DATA 199
 DATA 200
 DATA 201
 DATA 202
 DATA 203
 DATA 204
 DATA 205
 DATA 206
 DATA 207
 DATA 208
 DATA 209
 DATA 210
 DATA 211
 DATA 212
 DATA 213
 DATA 214
 DATA 215
 DATA 216

APPENDIX CComputer Program Listing

In this Appendix, the computer programs utilized in this study are listed. These include the subroutine utilized for generating $U(0,1)$ random numbers and identified as *RAND*, together with the subroutine utilized for generating $[1-U(0,1)]$ random numbers, identified as *RXMO*. The user must employ the appropriate random number subroutine during the execution of a run, but he should never have both subroutines present simultaneously in any one run. The last listing in this Appendix is of the program referred to as *STATIC* (see Fig. 5.1); the user should note that this is an independent program and not a subroutine.

```

COMMON NCASES, NRUNS, I, K, L, N, WC, VC, TAM, T1, T2, TSC, TBC, TTV, TAMP, T1P, MAIN 1
1 T2P, TSCP, TBPC, TTVP, IDMA, ID1, ID2, IDSC, IDBC, IDTV, INMS, IN1, IN2, INSC, MAIN 2
2 INBC, INTV, AMINM, AMIN1, AMIN2, AMINSC, AMINBC, AMINTV, AMAXM, AMAX1, AMAX2 MAIN 3
3, AMAXSC, AMAXBC, AMAXTV, ISUD, IBUD, IWA1SL, IWA2SL, ISCSL, TRCSL, INDEX1, MAIN 4
4 INDEX2, I1, K1, L1, ICASE, IRUN, TTM, NDUML, NDUMMY, WGHT, VOL, TIME, IBREAK, MAIN 5
5 WT1MAX, WT2MAX, IDBRTV, INBRTV, BRKTV, NDAMMY, INDEX, ICHANG MAIN 6
DIMENSION WC(1000), VC(1000), N(20), TSC( 9,20), TBC(10,20), TTV(17,20) MAIN 7
1, TSCP( 9,20), TBPC(10,20), TTVP(17,20), IDSC( 9,20), IDBC(10,20), IDTV(MAIN 8
2 17,20), INSC( 9,20), INBC(10,20), INTV(17,20), AMINSC( 9,20), AMINBC(10MAIN 9
3,20), AMINTV(17,20), AMAXSC( 9,20), AMAXBC(10,20), AMAXTV(17,20), NDUMMMAIN 10
4 Y(20), IDBRTV(8,20), INBRTV(8,20), BRKTV(8,20), NDAMMY(20), WGHT(3), VOLMAIN 11
5(3), TIME(3) MAIN 12
3000 FORMAT(I2) MAIN 13
3100 FORMAT(1H1,18X,'SHIP TO SHORE UNLOADING SIMULATION.'////) MAIN 14
3110 FORMAT(6X,'THE NUMBER OF CASES TO BE INVESTIGATED IN THIS COMPUTERMAIN 15
1 RUN IS ',I2) MAIN 16
3200 FORMAT(1H1,'THIS RUN IS TERMINATED AT THIS STAGE BECAUSE ALL THE TMAIN 17
1 RANSFER VEHICLES'/' ARE MALFUNCTIONING.') MAIN 18
READ(5,3000) NCASES MAIN 19
WRITE(6,3100) MAIN 20
WRITE(6,3110) NCASES MAIN 21
ICASE=0 MAIN 22
1000 IRUN=0 MAIN 23
CALL INPUT MAIN 24
IDSC(6,1)=N(1) MAIN 25
IF(K-1) 101,102,101 MAIN 26
101 DO 100 KK=2,K MAIN 27
IDSC(6, KK)=IDSC(6, KK-1)+N(KK) MAIN 28
100 CONTINUE MAIN 29
102 N(1)=1 MAIN 30
IF(K-1) 103,104,103 MAIN 31
103 DO 105 KK=2,K MAIN 32
N(KK)=IDSC(6, KK-1)+1 MAIN 33
105 CONTINUE MAIN 34
104 NDUML=IDSC(6,K) MAIN 35
CALL INOUT MAIN 36

```

1100	DO 110 II=1,I	MAIN	37
	TTVP(7,II)=TTV(7,II)	MAIN	38
	INTV(14,II)=0	MAIN	39
110	CONTINUE	MAIN	40
	IRUN=IRUN+1	MAIN	41
	INDEX=0	MAIN	42
	INDEX1=0	MAIN	43
	INDEX2=0	MAIN	44
	IBREAK=I	MAIN	45
	CALL BEGIN	MAIN	46
	IF(IBREAK) 2001,2001,1200	MAIN	47
2001	DO 2002 II=1,I	MAIN	48
	IF(INTV(14,II)) 2003,2002,2003	MAIN	49
2003	IDTV(8,II)=0	MAIN	50
	TTVP(8,II)=10.**70	MAIN	51
2002	CONTINUE	MAIN	52
	WRITE(6,3200)	MAIN	53
	GO TO 1400	MAIN	54
1200	DO 120 KK=1,K	MAIN	55
	IF(INSC(6,KK)) 120,121,120	MAIN	56
120	CONTINUE	MAIN	57
	CALL FIN	MAIN	58
	CONTINUE	MAIN	59
3400	FORMAT(3(F8.1,1X))	MAIN	60
	L1=1	MAIN	61
	IF(L-1) 3760,3710,3760	MAIN	62
3760	L2=1	MAIN	63
3700	L2=L2+1	MAIN	64
	IF(AMAXBC(5,L1)-AMAXBC(5,L2)) 3720,3730,3730	MAIN	65
3730	LEND=L1	MAIN	66
3750	IF(L2-L) 3700,3740,3740	MAIN	67
3720	LEND=L2	MAIN	68
	L1=L2	MAIN	69
	GO TO 3750	MAIN	70
3710	LEND=L1	MAIN	71
3740	II=1	MAIN	72

IF(I-1) 3860,3810,3860	MAIN 73
3860 I2=1	MAIN 74
3800 I2=I2+1	MAIN 75
IF(AMAXTV(8,I1)-AMAXTV(8,I2)) 3820,3830,3830	MAIN 76
3830 IEND=I1	MAIN 77
3850 IF(I2-I) 3800,3840,3840	MAIN 78
3820 IEND=I2	MAIN 79
I1=I2	MAIN 80
GO TO 3850	MAIN 81
3810 IEND=I1	MAIN 82
3840 CONTINUE	MAIN 83
WRITE(7,3400) TTM,AMAXBC(5,LEND),AMAXTV(8,IEND)	MAIN 84
GO TO 1300	MAIN 85
121 CONTINUE	MAIN 86
GO TO (4001,4002,4003,4004,4001,4002,4003,4004),IWA1SL	MAIN 87
4001 CONTINUE	MAIN 88
CALL ASLTVA	MAIN 89
CONTINUE	MAIN 90
GO TO 4000	MAIN 91
4002 CONTINUE	MAIN 92
CALL ASLTVB	MAIN 93
CONTINUE	MAIN 94
GO TO 4000	MAIN 95
4003 CONTINUE	MAIN 96
CALL ASLTVC	MAIN 97
CONTINUE	MAIN 98
GO TO 4000	MAIN 99
4004 CONTINUE	MAIN 100
CALL ASLTVD	MAIN 101
CONTINUE	MAIN 102
GO TO 4000	MAIN 103
4000 IF(IDTV(8,I1)-1)1300,131,130	MAIN 104
131 CONTINUE	MAIN 105
GO TO (4101,4102,4102),ISCSL	MAIN 106
4101 CONTINUE	MAIN 107
CALL SLSCA	MAIN 108

CONTINUE	MAIN 109
GO TO 4100	MAIN 110
4102 CONTINUE	MAIN 111
CALL SLSCB	MAIN 112
CONTINUE	MAIN 113
GO TO 4100	MAIN 114
4100 IF (INDEX1) 1500,141,1501	MAIN 115
1500 CONTINUE	MAIN 116
GO TO (131,131,4103),ISCSL	MAIN 117
4103 CONTINUE	MAIN 118
CALL SLSCC	MAIN 119
CONTINUE	MAIN 120
GO TO 141	MAIN 121
1501 CONTINUE	MAIN 122
GO TO (4011,4012,4013,4014,4011,4012,4013,4014),IWAISL	MAIN 123
4011 CONTINUE	MAIN 124
CALL ASLTVA	MAIN 125
CONTINUE	MAIN 126
GO TO 4010	MAIN 127
4012 CONTINUE	MAIN 128
CALL ASLTVB	MAIN 129
CONTINUE	MAIN 130
GO TO 4010	MAIN 131
4013 CONTINUE	MAIN 132
CALL ASLTVC	MAIN 133
CONTINUE	MAIN 134
GO TO 4010	MAIN 135
4014 CONTINUE	MAIN 136
CALL ASLTVD	MAIN 137
CONTINUE	MAIN 138
GO TO 4010	MAIN 139
4010 IF (IDTV(8,I1)-1) 1300,1502,130	MAIN 140
1502 CONTINUE	MAIN 141
GO TO (131,131,131,131,1503,1503,1503,1503),IWAISL	MAIN 142
1503 CONTINUE	MAIN 143
CALL ASLTVE	MAIN 144

CONTINUE	MAIN 145
CALL SLSCB	MAIN 146
CONTINUE	MAIN 147
GO TO 4100	MAIN 148
141 CONTINUE	MAIN 149
CALL LOAD	MAIN 150
IF(IBREAK) 2001,2001,1200	MAIN 151
130 CONTINUE	MAIN 152
GO TO (4201,4202),IBCSL	MAIN 153
4201 CONTINUE	MAIN 154
CALL SLBCA	MAIN 155
CONTINUE	MAIN 156
GO TO 4200	MAIN 157
4202 CONTINUE	MAIN 158
CALL SLBCB	MAIN 159
CONTINUE	MAIN 160
GO TO 4200	MAIN 161
4200 IF(INDEX2)130,151,121	MAIN 162
151 CONTINUE	MAIN 163
CALL UNLOAD	MAIN 164
IF(IBREAK) 2001,2001,121	MAIN 165
1400 KL=K-1	MAIN 166
DO 1401 KK=1,KL	MAIN 167
IDSC(6,KK)=N(KK+1)-1	MAIN 168
1401 CONTINUE	MAIN 169
IDSC(6,K)=NDUML	MAIN 170
GO TO 1402	MAIN 171
1300 CONTINUE	MAIN 172
1402 IF (IRUN-NRUNS) 1100,1403,1403	MAIN 173
1403 CONTINUE	MAIN 174
IF (ICASE-NCASES) 1000,1404,1404	MAIN 175
1404 CONTINUE	MAIN 176
END	MAIN 177

SUBROUTINE INPUT	INPT	1
COMMON NCASES, NRUNS, I, K, L, N, WC, VC, TAM, T1, T2, TSC, TBC, TTV, TAMP, T1P,	INPT	2
1 T2P, TSCP, TBCP, TTVP, IDMA, ID1, ID2, IDSC, IDBC, IDTV, INMS, IN1, IN2, INSC,	INPT	3
2 INBC, INTV, AMINM, AMIN1, AMIN2, AMINSC, AMINBC, AMINTV, AMAXM, AMAX1, AMAX2	INPT	4
3, AMAXSC, AMAXBC, AMAXTV, ISUD, IBUD, IWA1SL, IWA2SL, TSCSL, IBCSL, INDEX1,	INPT	5
4 INDEX2, I1, K1, L1, ICASE, IRUN, TTM, NDUML, NDUMMY, WGHT, VOL, TIME, IBREAK,	INPT	6
5 WT1MAX, WT2MAX, IDBRTV, INBRTV, BRKTV, NDAMMY, INDEX, ICHANG	INPT	7
DIMENSION WC(1000), VC(1000), N(20), TSC(9, 20), TBC(10, 20), TTV(17, 20)	INPT	8
1, TSCP(9, 20), TBCP(10, 20), TTVP(17, 20), IDSC(9, 20), IDBC(10, 20), IDTV(INPT	9
2 17, 20), INSC(9, 20), INBC(10, 20), INTV(17, 20), AMINSC(9, 20), AMINBC(10	INPT	10
3, 20), AMINTV(17, 20), AMAXSC(9, 20), AMAXBC(10, 20), AMAXTV(17, 20), NDUM	INPT	11
4 Y(20), IDBRTV(8, 20), INBRTV(8, 20), BRKTV(8, 20), NDAMMY(20), WGHT(3), VOL	INPT	12
5(3), TIME(3)	INPT	13
1000 FORMAT(20I4)	INPT	14
1100 FORMAT(20F4.0)	INPT	15
1200 FORMAT(6(F5.2, 1X, F4.0, 2X))	INPT	16
1300 FORMAT(6(F4.0, 1X, F5.0, 2X))	INPT	17
1400 FORMAT(I10, 2F10.5)	INPT	18
1500 FORMAT(7(I1, 1X))	INPT	19
1600 FORMAT(3(3A4))	INPT	20
1450 FORMAT(I2, I10, F6.4)	INPT	21
1440 FORMAT(2F10.2)	INPT	22
READ(5, 1000) NRUNS	INPT	23
READ(5, 1000) I, K, L	INPT	24
READ(5, 1000) (N(KK), KK=1, K)	INPT	25
NN=0	INPT	26
DO 100 KK=1, K	INPT	27
NN=NN+N(KK)	INPT	28
100 CONTINUE	INPT	29
READ(5, 1200) (WC(NNN), VC(NNN), NNN=1, NN)	INPT	30
READ(5, 1300) (AMAXTV(6, II), AMAXTV(7, II), II=1, I)	INPT	31
READ(5, 1100) TAM, T1, T2	INPT	32
DO 400 JJ=1, 5	INPT	33
CONTINUE	INPT	34
READ(5, 1100) (TSC(JJ, KK), KK=1, K)	INPT	35
400 CONTINUE	INPT	36

```

      DO 410 JJ=7,9
      CONTINUE
      READ(5,1100) (TSC(JJ,KK),KK=1,K)
410  CONTINUE
      DO 420 JJ=1,4
      CONTINUE
      READ(5,1100) (TBC(JJ,LL),LL=1,L)
420  CONTINUE
      DO 430 JJ=6,10
      CONTINUE
      READ(5,1100) (TBC(JJ,LL),LL=1,L)
430  CONTINUE
      DO 440 JJ=1,2
      CONTINUE
      READ(5,1100) (TTV(JJ,II),II=1,I)
440  CONTINUE
      DO 450 JJ=4,7
      CONTINUE
      READ(5,1100) (TTV(JJ,II),II=1,I)
450  CONTINUE
      DO 460 JJ=9,11
      CONTINUE
      READ(5,1100) (TTV(JJ,II),II=1,I)
460  CONTINUE
      READ(5,1100) (TTV(13,II),II=1,I)
      DO 470 JJ=15,17
      CONTINUE
      READ(5,1100) (TTV(JJ,II),II=1,I)
470  CONTINUE
      READ(5,1000) IDMA,ID1,ID2
      DO 480 JJ=1,5
      CONTINUE
      READ(5,1000) (IDSC(JJ,KK),KK=1,K)
480  CONTINUE
      DO 490 JJ=7,9
      CONTINUE

```

```

INPT  37
INPT  38
INPT  39
INPT  40
INPT  41
INPT  42
INPT  43
INPT  44
INPT  45
INPT  46
INPT  47
INPT  48
INPT  49
INPT  50
INPT  51
INPT  52
INPT  53
INPT  54
INPT  55
INPT  56
INPT  57
INPT  58
INPT  59
INPT  60
INPT  61
INPT  62
INPT  63
INPT  64
INPT  65
INPT  66
INPT  67
INPT  68
INPT  69
INPT  70
INPT  71
INPT  72

```

	READ(5,1000) (IDSC(JJ, KK), KK=1, K)	INPT 73
490	CONTINUE	INPT 74
	DO 500 JJ=1, 4	INPT 75
	CONTINUE	INPT 76
	READ(5,1000) (IDBC(JJ, LL), LL=1, L)	INPT 77
500	CONTINUE	INPT 78
	DO 510 JJ=6, 10	INPT 79
	CONTINUE	INPT 80
	READ(5,1000) (IDBC(JJ, LL), LL=1, L)	INPT 81
510	CONTINUE	INPT 82
	DO 520 JJ=1, 5	INPT 83
	CONTINUE	INPT 84
	READ(5,1000) (IDTV(JJ, II), II=1, I)	INPT 85
520	CONTINUE	INPT 86
	DO 530 JJ=9, 13	INPT 87
	CONTINUE	INPT 88
	READ(5,1000) (IDTV(JJ, II), II=1, I)	INPT 89
530	CONTINUE	INPT 90
	DO 540 JJ=15, 17	INPT 91
	CONTINUE	INPT 92
	READ(5,1000) (IDTV(JJ, II), II=1, I)	INPT 93
540	CONTINUE	INPT 94
	GO TO (2000, 2001), IDMA	INPT 95
2001	READ(5,1400) INMS, AMINM, AMAXM	INPT 96
	GO TO 2000	INPT 97
2000	CONTINUE	INPT 98
	GO TO (2010, 2011), ID1	INPT 99
2011	READ(5,1400) IN1, AMIN1, AMAX1	INPT 100
	GO TO 2010	INPT 101
2010	CONTINUE	INPT 102
	GO TO (2020, 2021), ID2	INPT 103
2021	READ(5,1400) IN2, AMIN2, AMAX2	INPT 104
	GO TO 2020	INPT 105
2020	CONTINUE	INPT 106
	JLOW=1	INPT 107
	JHIGH=5	INPT 108

DO 230 J=1,2	INPT 109
DO 231 JJ=JLOW,JHIGH	INPT 110
DO 232 KK=1,K	INPT 111
IDD=IDSC(JJ,KK)	INPT 112
GO TO (232,2030),IDD	INPT 113
2030 CONTINUE	INPT 114
READ(5,1400) INSC(JJ,KK),AMINSC(JJ,KK),AMAXSC(JJ,KK)	INPT 115
GO TO 232	INPT 116
232 CONTINUE	INPT 117
231 CONTINUE	INPT 118
JLOW=7	INPT 119
JHIGH=9	INPT 120
230 CONTINUE	INPT 121
JLOW=1	INPT 122
JHIGH=4	INPT 123
DO 240 J=1,2	INPT 124
DO 241 JJ=JLOW,JHIGH	INPT 125
DO 242 LL=1,L	INPT 126
IDD=IDBC(JJ,LL)	INPT 127
GO TO (242,2040),IDD	INPT 128
2040 CONTINUE	INPT 129
READ(5,1400) INBC(JJ,LL),AMINBC(JJ,LL),AMAXBC(JJ,LL)	INPT 130
GO TO 242	INPT 131
242 CONTINUE	INPT 132
241 CONTINUE	INPT 133
JLOW=6	INPT 134
JHIGH=10	INPT 135
240 CONTINUE	INPT 136
DO 250 J=1,3	INPT 137
GO TO (255,256,257),J	INPT 138
255 JLOW=1	INPT 139
JHIGH=5	INPT 140
GO TO 253	INPT 141
256 JLOW=9	INPT 142
JHIGH=13	INPT 143
GO TO 253	INPT 144

257	JLOW=15	INPT 145
	JHIGH=17	INPT 146
253	DO 251 JJ=JLOW,JHIGH	INPT 147
	DO 252 II=1,I	INPT 148
	IDD=IDTV(JJ,II)	INPT 149
	GO TO (252,2050),IDD	INPT 150
2050	CONTINUE	INPT 151
	READ(5,1400) INTV(JJ,II),AMINTV(JJ,II),AMAXTV(JJ,II)	INPT 152
	GO TO 252	INPT 153
252	CONTINUE	INPT 154
251	CONTINUE	INPT 155
250	CONTINUE	INPT 156
	READ(5,1440) WT1MAX,WT2MAX	INPT 157
	READ(5,1450) ((IDBRTV(JJ,II),INBRTV(JJ,II),BRKTV(JJ,II),JJ=1,8),II	INPT 158
	1=1,I)	INPT 159
	READ(5,1500) ISUD,IBUD,IWA1SL,IWA2SL,ISCSL,IBCSL,ICHANG	INPT 160
	ICASE=ICASE+1	INPT 161
	READ(5,1600) (WGHT(JJ),JJ=1,3),(VOL(JJ),JJ=1,3),(TIME(JJ),JJ=1,3)	INPT 162
	RETURN	INPT 163
	END	INPT 164

```

SUBROUTINE INCUT                                INCT  1
COMMON NCASES, NRUNS, I, K, L, N, WC, VC, TAM, T1, T2, TSC, TBC, TTV, TAMF, T1P, INCT  2
1T2P, TSCP, TBCP, TTVP, IDMA, ID1, ID2, IDSC, IDBC, IDTV, INMS, IN1, IN2, INSC, INOT  3
2INBC, INTV, AMINM, AMIN1, AMIN2, AMINSC, AMINBC, AMINTV, AMAXM, AMAX1, AMAX2 INOT  4
3, AMAXSC, AMAXBC, AMAXTV, ISUD, IBUD, IWA1SL, IWA2SL, ISCSL, IRCSL, INDEX1, INCT  5
4INDEX2, I1, K1, L1, ICASE, IRUN, TTM, NDUML, NDUMMY, WGHT, VOL, TIME, IBREAK, INOT  6
5WT1MAX, WT2MAX, ICRRTV, INBRTV, BRKTV, NDAMMY, INDEX, ICHANG INOT  7
DIMENSION WC(1000), VC(1000), N(20), TSC( 9,20), TBC(10,20), TTV(17,20) INOT  8
1, TSCP( 9,20), TBCP(10,20), TTVP(17,20), IDSC( 9,20), IDBC(10,20), IDTV(INCT  9
217,20), INSC( 9,20), INBC(10,20), INTV(17,20), AMINSC( 9,20), AMINBC(10 INOT 10
3,20), AMINTV(17,20), AMAXSC( 9,20), AMAXBC(10,20), AMAXTV(17,20), NDUMMINCT 11
4Y(20), IDBRTV(8,20), INBRTV(8,20), BRKTV(8,20), NDAMMY(20), WGHT(3), VOLINOT 12
5(3), TIME(3) INOT 13
1000 FORMAT(1H ,///) INCT 14
1010 FORMAT(1H ,61X, 'CASE NO. ', I2///) INOT 15
1020 FORMAT(6X, 'THE NUMBER OF TEST RUNS TO BE INVESTIGATED IN THIS CASEINOT 16
1 IS ', I2///) INCT 17
1030 FORMAT(1H ,55X, 'TEST RUN NO. ', I4///) INCT 18
1040 FORMAT(1H , 'NUMBER OF T.V. INVOLVED IN THIS CASE IS ', I4//1H , 'NINOT 19
1NUMBER OF S.U.F. INVOLVED IN THIS CASE IS ', I4//1H , 'NUMBER OF B.U.INOT 20
2F. INVOLVED IN THIS CASE IS ', I4) INCT 21
1100 FORMAT(1H1,1H , 'PAYLOAD CHARACTERISTICS'/1H ,1H(, 'THE WGT UNITS AINCT 22
1RE ',3A4, ' AND THE SPACE UNITS ARE ',3A4,1H)///) INCT 23
1110 FORMAT(1H , 'PAYLOAD CHARACTERISTICS FOR S.U.F NO. ', I4/2H (, 'TOTALINOT 24
1 NUMBER OF PAYLOAD UNITS ', I4,1H)///) INCT 25
1120 FORMAT(1H , ' WGT SPACE WGT SPACE WGT SPACE WGT SPACE WGT INOT 26
1SPACE WGT SPACE'//) INOT 27
1130 FORMAT(1H ,F5.2,1X,F4.0,2X,F5.2,1X,F4.0,2X,F5.2,1X,F4.0,2X,F5.2,1XINCT 28
1,F4.0,2X,F5.2,1X,F4.0,2X,F5.2,1X,F4.0,2X) INOT 29
1140 FORMAT(1H1) INCT 30
1200 FORMAT(1H1,1H , 'TRANSFER VEHICLE PAYLOAD CAPACITY'///1H ,15X, 'WEIGINCT 31
1HT',15X, 'SPACE'//) INOT 32
1210 FORMAT(1H , 'T.V. NO. ', I2,4X,F6.1,1X,3A4,2X,F7.1,1X,3A4) INCT 33
1300 FORMAT(1H1,1H , 'MCTHER SHIP DESCRIPTION'///1H , 'TAM=', F6.2,1X,3A4/INCT 34
12H , 'T1=', F6.2,1X,3A4/2H , 'T2=', F6.2,1X,3A4) INCT 35
1400 FORMAT(1H1,1H , 'SHIP UNLCADING FACILITIES DESCRIPTION'///) INOT 36

```

1410	FORMAT(1H , 'TSC(', I2, ')=' , 20F6.2)	INCT	37
1500	FORMAT(1H1, 1H , 'BEACH UNLCADING FACILITIES DESCRIPTION'///)	INCT	38
1510	FORMAT(1H , 'TBC(', I2, ')=' , 20F6.2)	INCT	39
1600	FORMAT(1H1, 1H , 'TRANSFER VEHICLE DESCRIPTION'///)	INCT	40
1610	FORMAT(1H , 'TTV(', I2, ')=' , 10F7.2)	INCT	41
1700	FORMAT(1H1, 1H , 'PROCESS INDICATOR'///)	INCT	42
1710	FORMAT(1H , 'MCTHER SHIP OPERATION'///)	INCT	43
1720	FORMAT(1H , 'PROCESS ASSOCIATED WITH TAM IS DETERMINISTIC'//)	INOT	44
1730	FORMAT(1H , 'PROCESS ASSOCIATED WITH T1 IS DETERMINISTIC'//)	INCT	45
1740	FORMAT(1H , 'PROCESS ASSOCIATED WITH T2 IS DETERMINISTIC'//)	INOT	46
1750	FORMAT(1H , 'PROCESS ASSOCIATED WITH TAM IS STOCHASTIC DRAWN FROM'//INOT		47
	11H , 'U(', F10.5, ', ', F10.5, ') WITH A STARTING SEED EQUAL TO ', I10//)	INOT	48
1760	FORMAT(1H , 'PROCESS ASSOCIATED WITH T1 IS STOCHASTIC DRAWN FROM'//INOT		49
	11H , 'U(', F10.5, ', ', F10.5, ') WITH A STARTING SEED EQUAL TO ', I10//)	INOT	50
1770	FORMAT(1H , 'PROCESS ASSOCIATED WITH T2 IS STOCHASTIC DRAWN FROM'//INOT		51
	11H , 'U(', F10.5, ', ', F10.5, ') WITH A STARTING SEED EQUAL TO ', I10//)	INOT	52
1800	FORMAT(1H , 'SHIP UNLOADING FACILITIES OPERATION'///)	INOT	53
1810	FORMAT(1H , 'PROCESS ASSOCIATED WITH TSC(', I2, ') IS DETERMINISTIC'//INCT		54
	1)	INOT	55
1820	FORMAT(1H , 'PROCESS ASSOCIATED WITH TSC(', I2, ') IS STOCHASTIC DRAWINOT		56
	1N FROM'//1H , 'U(', F10.5, ', ', F10.5, ') WITH A STARTING SEED EQUAL TO INOT		57
	2', I10//)	INCT	58
1900	FORMAT(1H , 'BEACH UNLOADING FACILITIES OPERATION'///)	INCT	59
1910	FORMAT(1H , 'PROCESS ASSOCIATED WITH TBC(', I2, ') IS DETERMINISTIC'//INOT		60
	1)	INOT	61
1920	FORMAT(1H , 'PROCESS ASSOCIATED WITH TBC(', I2, ') IS STOCHASTIC DRAWINCT		62
	1N FROM'//1H , 'U(', F10.5, ', ', F10.5, ') WITH A STARTING SEED EQUAL TO INOT		63
	2', I10//)	INCT	64
2000	FORMAT(1H , 'TRANSFER VEHICLE OPERATION'///)	INOT	65
2010	FORMAT(1H , 'PROCESS ASSOCIATED WITH TTV(', I2, ') IS DETERMINISTIC'//INOT		66
	1)	INCT	67
2020	FORMAT(1H , 'PROCESS ASSOCIATED WITH TTV(', I2, ') IS STOCHASTIC DRAWINOT		68
	1N FROM'//1H , 'U(', F10.5, ', ', F10.5, ') WITH A STARTING SEED EQUAL TO INOT		69
	2', I10//)	INCT	70
1830	FORMAT(1H , 'SHIP UNLOADING FACILITY NO. ', I2//)	INCT	71
1930	FORMAT(1H , 'BEACH UNLOADING FACILITY NO. ', I2//)	INCT	72

2030	FORMAT(1H , 'TRANSFER VEHICLE NO. ', I2//)	INCT	73
1840	FORMAT(1H1)	INCT	74
2100	FORMAT(1H1, 1H , 'BREAKDOWN CONSIDERATIONS'////)	INOT	75
2110	FORMAT(1H , 'DURING PROCESS NO. ', I2, ' THERE IS NO BREAKDOWN DURING	INCT	76
	1 THE ENTIRE MISSION'//)	INOT	77
2120	FORMAT(1H , 'DURING PROCESS NO. ', I2, ' THE BREAKDOWN CONSIDERATIONS	SINOT	78
	1 ARE OBTAINED FROM'/1H , 'A U(0,1) DISTRIBUTION WITH A STARTING SEE	INOT	79
	2D EQUAL TO', I10, ' AND'/1H , 'A PROBABILITY OF BREAKDOWN EQUAL TO ',	INCT	80
	3F6.4//)	INOT	81
2200	FORMAT(1H1, 1H , 'USE STRATEGIES AND UNLOADING DISCIPLINES'////)	INCT	82
2210	FORMAT(1H , 'THE S.U.F. ARE TO OPERATE IN SEQUENCE'//)	INCT	83
2220	FORMAT(1H , 'THE S.U.F. ARE TO OPERATE IN PARALLEL'//)	INOT	84
2230	FORMAT(1H , 'THE B.U.F. ARE TO OPERATE IN SEQUENCE'//)	INCT	85
2240	FORMAT(1H , 'THE B.U.F. ARE TO OPERATE IN PARALLEL'//)	INOT	86
2250	FORMAT(1H , 'THE T.V. ARE SELECTED FROM W.A. 1 ACCORDING TO THE RUL	INCT	87
	IES OF ASLTV A'//)	INOT	88
2260	FORMAT(1H , 'THE T.V. ARE SELECTED FROM W.A. 1 ACCORDING TO THE RUL	INCT	89
	IES OF ASLTV B'//)	INOT	90
2261	FORMAT(1H , 'THE T.V. ARE SELECTED FROM W.A. 1 ACCORDING TO THE RUL	INCT	91
	IES OF ASLTV C'//)	INCT	92
2262	FORMAT(1H , 'THE T.V. ARE SELECTED FROM W.A. 1 ACCORDING TO THE RUL	INCT	93
	IES OF ASLTV D'//)	INOT	94
2263	FORMAT(1H , 'THE T.V. ARE SELECTED FROM W.A. 1 ACCORDING TO THE RUL	INCT	95
	IES OF ASLTV E'//)	INCT	96
2270	FORMAT(1H , 'THE T.V. ARE SELECTED FROM W.A. 2 ACCORDING TO THE RUL	INOT	97
	IES OF BSLTV A'//)	INCT	98
2280	FORMAT(1H , 'THE T.V. ARE SELECTED FROM W.A. 2 ACCORDING TO THE RUL	INCT	99
	IES OF BSLTV B'//)	INOT	100
2281	FORMAT(1H , 'THE T.V. ARE SELECTED FROM W.A. 2 ACCORDING TO THE RUL	INCT	101
	IES OF BSLTV C'//)	INOT	102
2282	FORMAT(1H , 'THE T.V. ARE SELECTED FROM W.A. 2 ACCORDING TO THE RUL	INCT	103
	IES OF BSLTV D'//)	INOT	104
2283	FORMAT(1H , 'THE ABOVE MENTIONED T.V. USE STRATEGIES ARE USED ONLY	INOT	105
	1 FOR THE INITIAL STAGES.'/1H , 'THE INSTANT THE SYSTEM BECCMES VOLUM	INCT	106
	2E LIMITED USE STRATEGIES'/1H , 'ASLTV A AND BSLTV A OR ASLTV C AND BSL	INOT	107
	3TV C COME INTO EFFECT.'/1H , 'SIMILARLY THE INSTANT THE SYSTEM BECCM	INOT	108

```

4ES WEIGHT LIMITED USE STRATEGIES'/1H , 'ASLTVB AND BSLTVB CR ASLTVDINOT 109
5 AND BSLTVD COME INTO EFFECT. '/') INOT 110
2290 FORMAT(1H , 'THE S.U.F. ARE SELECTED ACCORDING TO THE RULES CF SLSCINOT 111
1A'//) INOT 112
2300 FORMAT(1H , 'THE S.U.F. ARE SELECTED ACCORDING TO THE RULES CF SLSCINOT 113
1B'//) INOT 114
2301 FORMAT(1H , 'THE S.U.F. ARE SELECTED ACCORDING TO THE RULES CF SLSCINOT 115
1C'//) INOT 116
2310 FORMAT(1H , 'THE B.U.F. ARE SELECTED ACCORDING TO THE RULES CF SLBCINOT 117
1A'//) INOT 118
2320 FORMAT(1H , 'THE B.U.F. ARE SELECTED ACCORDING TO THE RULES CF SLBCINOT 119
1B'//) INOT 120
2400 FORMAT(1H1,1H , 'MISCELLANECUS INFCRMATION'////) INOT 121
2410 FCRMAT(1H , 'THE MAXIMUM WAITING TIME CF ANY T.V. DURING THE ENTIREINOT 122
1 MISSION IN W.A. 1'/1H , 'IS EXPECTED TO BE ',F10.2,1H ,3A4//) INOT 123
2420 FCRMAT(1H , 'THE MAXIMUM WAITING TIME CF ANY T.V. DURING THE ENTIREINOT 124
1 MISSION IN W.A. 2'/1H , 'IS EXPECTED TO BE ',F10.2,1H ,3A4//) INOT 125
2430 FCRMAT(1H , 'THE WEIGHT UNITS IN THIS CASE ARE ',3A4//) INOT 126
2440 FORMAT(1H , 'THE SPACE UNITS IN THIS CASE ARE ',3A4//) INOT 127
2450 FORMAT(1H , 'THE TIME UNITS IN THIS CASE ARE ',3A4//) INOT 128
WRITE(6,1000) INOT 129
WRITE(6,1010) ICASE INOT 130
WRITE(6,1020) NRUNS INOT 131
IRUN=IRUN+1 INOT 132
WRITE(6,1030) IRUN INOT 133
IRUN=IRUN-1 INOT 134
WRITE(6,1040) I,K,L INOT 135
WRITE(6,1100) (WGHT(JJ),JJ=1,3),(VCL(JJ),JJ=1,3) INOT 136
DC 100 JJ=1,K INOT 137
NCGOUNT=IDSC(6,JJ)-N(JJ)+1 INOT 138
WRITE(6,1110) JJ,NCGOUNT INOT 139
WRITE(6,1120) INOT 140
JLOW=N(JJ) INOT 141
JHIGH=IDSC(6,JJ) INOT 142
WRITE(6,1130) (WC(JJJ),VC(JJJ),JJJ=JLCW,JHIGH) INOT 143
WRITE(6,1140) INOT 144

```

100	CONTINUE	INCT	145
	WRITE(6,1200)	INCT	146
	DO 110 JJ=1,I	INCT	147
	WRITE(6,1210) JJ,AMAXTV(6, JJ), (WGHT(JJJ), JJJ=1,3), AMAXTV(7, JJ), (VC	INCT	148
	1L(JJJ), JJJ=1,3)	INCT	149
110	CONTINUE	INCT	150
	WRITE(6,1300) TAM, (TIME(JJJ), JJJ=1,3), T1, (TIME(JJJ), JJJ=1,3), T2, (T	INCT	151
	1IME(JJJ), JJJ=1,3)	INCT	152
	WRITE(6,1400)	INCT	153
	DO 120 JJ=1,5	INCT	154
	WRITE(6,1410) JJ, (TSC(JJ, KK), KK=1, K)	INCT	155
120	CONTINUE	INCT	156
	DO 130 JJ=7,9	INCT	157
	WRITE(6,1410) JJ, (TSC(JJ, KK), KK=1, K)	INCT	158
130	CONTINUE	INCT	159
	WRITE(6,1500)	INCT	160
	DO 140 JJ=1,4	INCT	161
	WRITE(6,1510) JJ, (TBC(JJ, LL), LL=1, L)	INCT	162
140	CONTINUE	INCT	163
	DO 150 JJ=6,10	INCT	164
	WRITE(6,1510) JJ, (TBC(JJ, LL), LL=1, L)	INCT	165
150	CONTINUE	INCT	166
	WRITE(6,1600)	INCT	167
	DO 160 JJ=1,2	INCT	168
	WRITE(6,1610) JJ, (TTV(JJ, II), II=1, I)	INCT	169
160	CONTINUE	INCT	170
	DO 170 JJ=4,7	INCT	171
	WRITE(6,1610) JJ, (TTV(JJ, II), II=1, I)	INCT	172
170	CONTINUE	INCT	173
	DO 180 JJ=9,11	INCT	174
	WRITE(6,1610) JJ, (TTV(JJ, II), II=1, I)	INCT	175
180	CONTINUE	INCT	176
	JJ=13	INCT	177
	WRITE(6,1610) JJ, (TTV(JJ, II), II=1, I)	INCT	178
	DO 190 JJ=15,17	INCT	179
	WRITE(6,1610) JJ, (TTV(JJ, II), II=1, I)	INCT	180

190	CONTINUE	INCT 181
	WRITE(6,1700)	INOT 182
	WRITE(6,171C)	INCT 183
	GO TO (3000,301C),IDMA	INOT 184
3000	CONTINUE	INCT 185
	WRITE(6,172C)	INCT 186
	GO TO 3020	INOT 187
3010	CONTINUE	INCT 188
	WRITE(6,175C) AMINM,AMAXM,INMS	INOT 189
	GO TO 3020	INCT 190
3020	CONTINUE	INCT 191
	GO TO (3100,311C),ID1	INOT 192
3100	CONTINUE	INCT 193
	WRITE(6,173C)	INOT 194
	GO TO 3120	INCT 195
3110	CONTINUE	INCT 196
	WRITE(6,176C) AMIN1,AMAX1,IN1	INOT 197
	GO TO 3120	INCT 198
3120	CONTINUE	INCT 199
	GO TO (3200,321C),ID2	INOT 200
3200	CONTINUE	INCT 201
	WRITE(6,174C)	INOT 202
	GO TO 3220	INCT 203
3210	CONTINUE	INOT 204
	WRITE(6,177C) AMIN2,AMAX2,IN2	INOT 205
	GO TO 3220	INCT 206
3220	CONTINUE	INCT 207
	WRITE(6,170C)	INOT 208
	WRITE(6,180C)	INCT 209
	DO 200 KK=1,K	INOT 210
	WRITE(6,183C) KK	INCT 211
	JLOW=1	INOT 212
	JHIGH=5	INCT 213
	DO 210 J=1,2	INOT 214
	DO 220 JJ=JLOW,JHIGH	INOT 215
	IDC=IDSC(JJ,KK)	INOT 216

	GO TO (3300,3310),IDD	INOT 217
3300	CONTINUE	INCT 218
	WRITE (6,1810) JJ	INOT 219
	GO TO 220	INCT 220
3310	CONTINUE	INCT 221
	WRITE(6,1820) JJ,AMINSC(JJ,KK),AMAXSC(JJ,KK),INSC(JJ,KK)	INCT 222
	GO TO 220	INCT 223
220	CONTINUE	INOT 224
	JLOW=7	INCT 225
	JHIGH=9	INCT 226
210	CONTINUE	INCT 227
	IF (KK-K) 3320,200,3320	INCT 228
3320	CONTINUE	INOT 229
	WRITE(6,1840)	INCT 230
200	CONTINUE	INCT 231
	WRITE(6,1700)	INOT 232
	WRITE(6,1900)	INCT 233
	DO 230 LL=1,L	INCT 234
	WRITE(6,1930) LL	INCT 235
	JLOW=1	INCT 236
	JHIGH=4	INOT 237
	DO 240 J=1,2	INCT 238
	DO 250 JJ=JLOW,JHIGH	INOT 239
	IDD=IDBC(JJ,LL)	INCT 240
	GO TO (3400,3410),IDD	INOT 241
3400	CONTINUE	INOT 242
	WRITE(6,1910) JJ	INCT 243
	GO TO 250	INOT 244
3410	CONTINUE	INCT 245
	WRITE(6,1920) JJ,AMINBC(JJ,LL),AMAXBC(JJ,LL),INBC(JJ,LL)	INCT 246
	GO TO 250	INCT 247
250	CONTINUE	INCT 248
	JLOW=6	INOT 249
	JHIGH=10	INCT 250
240	CONTINUE	INCT 251
	IF(LL-L) 3420,230,3420	INCT 252

3420	CONTINUE	INCT 253
	WRITE(6,1840)	INCT 254
230	CONTINUE	INCT 255
	WRITE(6,1700)	INCT 256
	WRITE(6,2000)	INCT 257
	DC 260 II=1,I	INCT 258
	WRITE(6,2030)II	INOT 259
	DC 270 J=1,3	INCT 260
	GO TO (271,272,273),J	INOT 261
271	JLOW=1	INOT 262
	JHIGH=5	INCT 263
	GO TO 281	INOT 264
272	JLCW=9	INCT 265
	JHIGH=13	INOT 266
	GO TO 281	INCT 267
273	JLCW=15	INCT 268
	JHIGH=17	INOT 269
281	DO 280 JJ=JLOW,JHIGH	INCT 270
	IDD=IDTV(JJ,II)	INOT 271
	GO TO (3500,3510),IDD	INCT 272
3500	CONTINUE	INCT 273
	WRITE(6,2010) JJ	INCT 274
	GO TO 280	INCT 275
3510	CONTINUE	INCT 276
	WRITE(6,2020) JJ,AMINTV(JJ,II),AMAXTV(JJ,II),INTV(JJ,II)	INOT 277
	GO TO 280	INCT 278
280	CONTINUE	INOT 279
270	CONTINUE	INCT 280
	IF(II-I) 3520,260,3520	INCT 281
3520	CONTINUE	INOT 282
	WRITE(6,1840)	INCT 283
260	CONTINUE	INOT 284
	WRITE(6,2100)	INCT 285
	DC 290 II=1,I	INCT 286
	WRITE(6,2030) II	INOT 287
	DC 300 JJ=1,8	INCT 288

IDD=IDBRTV(JJ,II)	INOT 289
GO TO (3600,3610),IDD	INOT 290
3600 CONTINUE	INOT 291
WRITE(6,2110) JJ	INOT 292
GO TO 300	INOT 293
3610 CONTINUE	INOT 294
WRITE(6,2120) JJ,INBRTV(JJ,II),BRKTV(JJ,II)	INOT 295
GO TO 300	INOT 296
300 CONTINUE	INOT 297
IF(II-I) 3620,290,3620	INOT 298
3620 CONTINUE	INOT 299
WRITE(6,1840)	INOT 300
290 CONTINUE	INOT 301
WRITE(6,2200)	INOT 302
GO TO (3700,3710),ISUD	INOT 303
3700 CONTINUE	INOT 304
WRITE(6,2220)	INOT 305
GO TO 3720	INOT 306
3710 CONTINUE	INOT 307
WRITE(6,2210)	INOT 308
GO TO 3720	INOT 309
3720 CONTINUE	INOT 310
GO TO (3800,3810),IBUD	INOT 311
3800 CONTINUE	INOT 312
WRITE(6,2240)	INOT 313
GO TO 3820	INOT 314
3810 CONTINUE	INOT 315
WRITE(6,2230)	INOT 316
GO TO 3820	INOT 317
3820 CONTINUE	INOT 318
GO TO (3900,3910,3911,3912,3913,3913,3913,3913),IWA1SL	INOT 319
3900 CONTINUE	INOT 320
WRITE(6,2250)	INOT 321
GO TO 3920	INOT 322
3910 CONTINUE	INOT 323
WRITE(6,2260)	INOT 324

GO TO 3920	INOT 325
3911 CONTINUE	INOT 326
WRITE(6,2261)	INOT 327
GO TO 3920	INOT 328
3912 CONTINUE	INCT 329
WRITE(6,2262)	INCT 330
GO TO 3920	INOT 331
3913 CONTINUE	INCT 332
WRITE(6,2263)	INOT 333
GO TO 3920	INOT 334
3920 CONTINUE	INCT 335
GO TO (4000,4010,4011,4012),IWA2SL	INOT 336
4000 CONTINUE	INCT 337
WRITE(6,2270)	INOT 338
GO TO 4020	INCT 339
4010 CONTINUE	INOT 340
WRITE(6,2280)	INOT 341
GO TO 4020	INOT 342
4011 CONTINUE	INCT 343
WRITE(6,2281)	INCT 344
GO TO 4020	INCT 345
4012 CONTINUE	INCT 346
WRITE(6,2282)	INOT 347
GO TO 4020	INOT 348
4020 CONTINUE	INCT 349
GO TO (4030,4040),ICHANG	INOT 350
4040 CONTINUE	INOT 351
WRITE (6,2283)	INOT 352
4030 CONTINUE	INOT 353
GO TO (4100,4110,4111),ISCSL	INCT 354
4100 CONTINUE	INOT 355
WRITE(6,2290)	INCT 356
GO TO 4120	INCT 357
4110 CONTINUE	INCT 358
WRITE(6,2300)	INOT 359
GO TO 4120	INCT 360

4111	CONTINUE	INCT 361
	WRITE(6,2301)	INCT 362
	GO TO 4120	INCT 363
4120	CONTINUE	INOT 364
	GO TO (4200,4210), IBCSL	INOT 365
4200	CONTINUE	INOT 366
	WRITE(6,2310)	INOT 367
	GO TO 4220	INCT 368
4210	CONTINUE	INCT 369
	WRITE(6,2320)	INCT 370
	GO TO 4220	INCT 371
4220	CONTINUE	INCT 372
	WRITE(6,2400)	INOT 373
	WRITE(6,2410) WT1MAX	INCT 374
	WRITE(6,2420) WT2MAX	INCT 375
	WRITE(6,2430) (WGHT(JJ),JJ=1,3)	INOT 376
	WRITE(6,2440) (VOL(JJ),JJ=1,3)	INOT 377
	WRITE(6,2450) (TIME(JJ),JJ=1,3)	INCT 378
	RETURN	INOT 379
	END	INCT 380

```

SUBROUTINE BEGIN                                BEGN  1
COMMON NCASES, NRUNS, I, K, L, N, WC, VC, TAM, T1, T2, TSC, TBC, TTV, TAMP, T1P, BEGN  2
1T2P, TSCP, TBCP, TTVP, IDMA, ID1, ID2, IDSC, IDBC, IDTV, INMS, IN1, IN2, INSC, BEGN  3
2INBC, INTV, AMINM, AMIN1, AMIN2, AMINSC, AMINBC, AMINTV, AMAXM, AMAX1, AMAX2 BEGN  4
3, AMAXSC, AMAXBC, AMAXTV, ISUD, IBUD, IWA1SL, IWA2SL, ISCSL, IBCSL, INDEX1, BEGN  5
4INDEX2, I1, K1, L1, ICASE, IRUN, TTM, NDUML, NDUMMY, WGT, VOL, TIME, IBREAK, BEGN  6
5WT1MAX, WT2MAX, IDBRTV, INBRTV, BRKTV, NDAMMY, INDEX, ICHANG BEGN  7
DIMENSION WC(1000), VC(1000), N(20), TSC( 9,20), TBC(10,20), TTV(17,20) BEGN  8
1, TSCP( 9,20), TBCP(10,20), TTVP(17,20), IDSC( 9,20), IDBC(10,20), IDTV(BEGN  9
217,20), INSC( 9,20), INBC(10,20), INTV(17,20), AMINSC( 9,20), AMINBC(10 BEGN 10
3,20), AMINTV(17,20), AMAXSC( 9,20), AMAXBC(10,20), AMAXTV(17,20), NDUMM BEGN 11
4Y(20), IDBRTV(8,20), INBRTV(8,20), BRKTV(8,20), NDAMMY(20), WGT(3), VOL BEGN 12
5(3), TIME(3) BEGN 13
1000 FORMAT(1H1,60X,'CASE NO. ',I2/57X,'TEST RUN NO. ',I2//27X,'MISSION BEGN 14
1 DESCRIPTION.'/2H (,'THE UNITS OF TIME ARE ',3A4,1H)//' MOTHER SHIP BEGN 15
2P ARRIVAL AND MOORING OPERATION,') BEGN 16
1010 FORMAT(' THE MOTHER SHIP ARRIVED AT THE THEATER OF OPERATIONS ',F8 BEGN 17
1.1,' UNITS OF'/' TIME AFTER THE START OF THE MISSION.')

```

1	W.A. 1.'/' FOR ANALYSIS PURPOSES IF AT THE TERMINATION OF THIS RUBEGN	37
2N	A T.V. IS FOUND'/' UNUSED THEN ALL DECISIONS MADE AT THIS STAGE BEGN	38
	3CONCERNING SUCH A T.V.'/' WILL BE FORFEITED.') BEGN	39
1310	FORMAT(' WITH THE ABOVE PROVISION T.V. NO. ',I2,' DEPARTED FROM ITBEGN	40
	1S BASE ',F8.1/' UNITS OF TIME AFTER THE START OF THE MISSION.') BEGN	41
1320	FORMAT(' T.V. NO. ',I2,' ARRIVED AT W.A. 1 ',F8.1,' UNITS OF TIME BEGN	42
	1AFTER THE START OF'/' THE MISSION.') BEGN	43
1400	FORMAT(1H ,////' T.V. BREAKDOWN CONSIDERATIONS.'////) BEGN	44
1410	FORMAT(' ALL TRANSFER VEHICLES HAVE SAFELY ENTERED W.A. 1.'////) BEGN	45
1420	FORMAT(1H ,////) BEGN	46
1430	FORMAT(' T.V. NO. ',I2,' IS NOT ALLOWED TO ENTER W.A. 1 AS IT IS CBEGN	47
	1CONSIDERED TO BE'/' MALFUNCTIONING. THE ABOVE CITED T.V. IS CONSIDBEGN	48
	2ERED LOST FROM CUR SYSTEM FOR THIS COMPUTER RUN.') BEGN	49
1200	FORMAT(1H1,'PREPARATION OF BEACH BASED UNLOADING FACILITIES.'/' FOREIGN	50
	1R ANALYSIS PURPOSES IF AT THE TERMINATION OF THIS RUN A BEACH BASEBEGN	51
	2D'/' UNLOADING FACILITY IS FOUND UNUSED THEN ALL DECISIONS MADE ATBEGN	52
	3 THIS'/' STAGE CONCERNING SUCH A FACILITY WILL BE FORFEITED.') BEGN	53
1201	FORMAT(2H (,'THE UNITS OF TIME ARE ',3A4,1H)////) BEGN	54
	GO TO (2000,2001),IDMA BEGN	55
2000	TAMP=0. BEGN	56
	GO TO 3000 BEGN	57
2001	CONTINUE BEGN	58
	CALL RANDU(INMS,INMS,TAMP) BEGN	59
	TAMP=(AMAXM-AMINM)*TAMP+AMINM-TAM BEGN	60
	GO TO 3000 BEGN	61
3000	CONTINUE BEGN	62
	GO TO (2010,2011),ID1 BEGN	63
2010	T1P=0. BEGN	64
	GO TO 3010 BEGN	65
2011	CONTINUE BEGN	66
	CALL RANDU(IN1,IN1,T1P) BEGN	67
	T1P=(AMAX1-AMIN1)*T1P+AMIN1 -T1 BEGN	68
	GO TO 3010 BEGN	69
3010	CONTINUE BEGN	70
	T1M=TAM+TAMP BEGN	71
	WRITE(6,1000) ICASE,IRUN,(TIME(JJ),JJ=1,3) BEGN	72

	WRITE(6,101C) TTM	BEGN 73
	TTM=TTM+T1+T1P	BEGN 74
	WRITE(6,102C) TTM	BEGN 75
	WRITE(6,110C) TTM	BEGN 76
	DO 100 KK=1,K	BEGN 77
	IDD=IDSC(1,KK)	BEGN 78
	GC TO (2020,2021),IDD	BEGN 79
2020	TSCP(1,KK)=C.	BEGN 80
	GC TO 3020	BEGN 81
2021	IND=INSC(1,KK)	BEGN 82
	CALL RANDU(IND,IND,TPD)	BEGN 83
	INSC(1,KK)=IND	BEGN 84
	TSCP(1,KK)=(AMAXSC(1,KK)-AMINSC(1,KK))*TPD+AMINSC(1,KK)-TSC(1,KK)	BEGN 85
	GO TO 3020	BEGN 86
3020	AMAXSC(6,KK)=TTM+TSC(1,KK)+TSCP(1,KK)	BEGN 87
	TSCP(6,KK)=TTM	BEGN 88
	INSC(6,KK)=C	BEGN 89
	WRITE(6,111C) KK,AMAXSC(6,KK)	BEGN 90
100	CONTINUE	BEGN 91
	WRITE(6,120C)	BEGN 92
	WRITE(6,1201) (TIME(JJ),JJ=1,3)	BEGN 93
	DO 110 LL=1,L	BEGN 94
	DO 111 JJ=1,3	BEGN 95
	IDD=IDBC(JJ,LL)	BEGN 96
	GC TO (2030,2031),IDD	BEGN 97
2030	TBCP(JJ,LL)=0.	BEGN 98
	GO TO 111	BEGN 99
2031	IND=INBC(JJ,LL)	BEGN 100
	CALL RANDU(IND,IND,TPD)	BEGN 101
	INBC(JJ,LL)=IND	BEGN 102
	TBCP(JJ,LL)=(AMAXBC(JJ,LL)-AMINBC(JJ,LL))*TPD+AMINBC(JJ,LL)-TBC(JJ,LL)	BEGN 103
	1J,LL)	BEGN 104
	GC TO 111	BEGN 105
111	CONTINUE	BEGN 106
	AMAXBC(5,LL)=TBC(1,LL)+TBCP(1,LL)	BEGN 107
	WRITE(6,1210) LL,AMAXBC(5,LL)	BEGN 108

TBCP(5,LL)=AMAXBC(5,LL)+TBC(2,LL)+TBCP(2,LL)	BEGN 109
WRITE(6,1220) TBCP(5,LL),LL	BEGN 110
AMAXBC(5,LL)=TBCP(5,LL)+TBC(3,LL)+TBCP(3,LL)	BEGN 111
WRITE(6,1230) LL,AMAXBC(5,LL)	BEGN 112
IDBC(5,LL)=C	BEGN 113
110 CONTINUE	BEGN 114
WRITE(6,1300)	BEGN 115
WRITE(6,1201) (TIME(JJ),JJ=1,3)	BEGN 116
DC 120 II=1,I	BEGN 117
DC 121 JJ=1,2	BEGN 118
IDD=IDTV(JJ,II)	BEGN 119
GO TO (2040,2041),IDD	BEGN 120
2040 TTVP(JJ,II)=0.	BEGN 121
GO TO 121	BEGN 122
2041 IND=INTV(JJ,II)	BEGN 123
CALL RANDU(IND,IND,TPD)	BEGN 124
INTV(JJ,II)=IND	BEGN 125
TTVP(JJ,II)=(AMAXTV(JJ,II)-AMINTV(JJ,II))*TPD+AMINTV(JJ,II)-TTV(JJ,	BEGN 126
1,II)	BEGN 127
GO TO 121	BEGN 128
121 CONTINUE	BEGN 129
AMAXTV(8,II)=TTV(1,II)+TTVP(1,II)	BEGN 130
WRITE(6,1310) II,AMAXTV(8,II)	BEGN 131
AMAXTV(8,II)=AMAXTV(8,II)+TTV(2,II)+TTVP(2,II)	BEGN 132
IDTV(8,II)=1	BEGN 133
IDTV(14,II)=0	BEGN 134
TTVP(8,II)=AMAXTV(8,II)	BEGN 135
TTVP(14,II)=10.**70	BEGN 136
120 CCNTINUE	BEGN 137
DC 130 II=1,I	BEGN 138
IDD=IDBRTV(1,II)	BEGN 139
GO TO (130,2050),IDD	BEGN 140
2050 IND=INBRTV(1,II)	BEGN 141
CALL RANDU(IND,IND,TPD)	BEGN 142
INBRTV(1,II)=IND	BEGN 143
IF(BRKTV(1,II)-TPD)130,130,3050	BEGN 144

3050	IBREAK=IBREAK-1	BEGN 145
	IF (IBREAK+1-I) 3062,3063,3062	BEGN 146
3063	CONTINUE	BEGN 147
	WRITE(6,140C)	BEGN 148
3062	INTV(14,II)=1	BEGN 149
	WRITE(6,1430) II	BEGN 150
	GO TO 130	BEGN 151
130	CONTINUE	BEGN 152
	DO 140 II=1,I	BEGN 153
	IF (IDBRTV(1,II)-1) 140,140,141	BEGN 154
140	CONTINUE	BEGN 155
	GO TO 3061	BEGN 156
141	IF (IBREAK-I) 3065,3066,3065	BEGN 157
3066	CONTINUE	BEGN 158
	WRITE(6,140C)	BEGN 159
	WRITE(6,141C)	BEGN 160
	GO TO 3061	BEGN 161
3065	IF (IBREAK) 3067,3067,3068	BEGN 162
3068	CONTINUE	BEGN 163
	WRITE(6,142C)	BEGN 164
3061	DO 150 II=1,I	BEGN 165
	IF (INTV(14,II))150,3069,150	BEGN 166
3069	CONTINUE	BEGN 167
	WRITE(6,132C) II,AMAXTV(8,II)	BEGN 168
150	CONTINUE	BEGN 169
3067	CONTINUE	BEGN 170
	RETURN	BEGN 171
	END	BEGN 172

SUBROUTINE ASLTVA	ATVA	1
COMMON NCASES, NRUNS, I, K, L, N, WC, VC, TAM, T1, T2, TSC, TBC, TTV, TAMP, T1P,	ATVA	2
1 T2P, TSCP, TBCP, TTVP, IDMA, ID1, ID2, IDSC, IDBC, IDTV, INMS, IN1, IN2, INSC,	ATVA	3
2 INBC, INTV, AMINM, AMIN1, AMIN2, AMINSC, AMINBC, AMINTV, AMAXM, AMAX1, AMAX2	ATVA	4
3, AMAXSC, AMAXBC, AMAXTV, ISUD, IBUD, IWA1SL, IWA2SL, ISCSL, IBCSL, INDEX1,	ATVA	5
4 INDEX2, I1, K1, L1, ICASE, IRUN, TTM, NDUML, NDUMMY, WGHT, VOL, TIME, IBREAK,	ATVA	6
5 WT1MAX, WT2MAX, IDBRTV, INBRTV, BRKTV, NDAMMY, INDEX, ICHANG	ATVA	7
DIMENSION WC(1000), VC(1000), N(20), TSC(9,20), TBC(10,20), TTV(17,20)	ATVA	8
1, TSCP(9,20), TBCP(10,20), TTVP(17,20), IDSC(9,20), IDBC(10,20), IDTV(ATVA	9
2 17,20), INSC(9,20), INBC(10,20), INTV(17,20), AMINSC(9,20), AMINBC(10	ATVA	10
3,20), AMINTV(17,20), AMAXSC(9,20), AMAXBC(10,20), AMAXTV(17,20), NDUMM	ATVA	11
4 Y(20), IDBRTV(8,20), INBRTV(8,20), BRKTV(8,20), NDAMMY(20), WGHT(3), VOL	ATVA	12
5(3), TIME(3)	ATVA	13
I1=1	ATVA	14
IF(I-1) 1000,1000,100	ATVA	15
100 I2=2	ATVA	16
150 IF(TTVP(8,I1)-TTVP(8,I2)) 110,120,130	ATVA	17
130 I1=I2	ATVA	18
110 IF(I2-I1) 140,2000,2000	ATVA	19
140 I2=I2+1	ATVA	20
GO TO 150	ATVA	21
120 IF(IDTV(8,I1)-1) 110,160,110	ATVA	22
160 A1=TTV(4,I1)+TTV(10,I1)+TTV(11,I1)	ATVA	23
A2=TTV(4,I2)+TTV(10,I2)+TTV(11,I2)	ATVA	24
IF((AMAXTV(7,I1)/A1)-(AMAXTV(7,I2)/A2)) 130,111,110	ATVA	25
111 IF((AMAXTV(6,I1)/A1)-(AMAXTV(6,I2)/A2)) 130,112,110	ATVA	26
112 IF(AMAXTV(7,I1)-AMAXTV(7,I2)) 130,113,110	ATVA	27
113 IF(AMAXTV(6,I1)-AMAXTV(6,I2)) 130,114,110	ATVA	28
114 IF(A1-A2) 110,110,130	ATVA	29
2000 IF(INTV(14,I1)) 2010,2020,2010	ATVA	30
2010 IDTV(8,I1)=0	ATVA	31
TTVP(8,I1)=10.**70	ATVA	32
I1=1	ATVA	33
GO TO 100	ATVA	34
2020 CONTINUE	ATVA	35
GO TO(1001,1002,1003,1004), IWA2SL	ATVA	36

1001	CONTINUE	ATVA	37
	CALL BSLTVA	ATVA	38
	CONTINUE	ATVA	39
	GO TO 1000	ATVA	40
1002	CONTINUE	ATVA	41
	CALL BSLTVB	ATVA	42
	CONTINUE	ATVA	43
	GO TO 1000	ATVA	44
1003	CONTINUE	ATVA	45
	CALL BSLTVC	ATVA	46
	CONTINUE	ATVA	47
	GO TO 1000	ATVA	48
1004	CONTINUE	ATVA	49
	CALL BSLTVD	ATVA	50
	CONTINUE	ATVA	51
	GO TO 1000	ATVA	52
1000	CONTINUE	ATVA	53
	RETURN	ATVA	54
	END	ATVA	55

SUBROUTINE ASLTVB	ATVB	1
COMMON NCASES, NRUNS, I, K, L, N, WC, VC, TAM, T1, T2, TSC, TBC, TTV, TAMP, T1P,	ATVB	2
1T2P, TSCP, TBCP, TTVP, IDMA, ID1, ID2, IDSC, ICBC, IDTV, INMS, IN1, IN2, INSC,	ATVB	3
2INBC, INTV, AMINM, AMIN1, AMIN2, AMINSC, AMINBC, AMINTV, AMAXM, AMAX1, AMAX2	ATVB	4
3, AMAXSC, AMAXBC, AMAXTV, ISUD, IBUD, IWA1SL, IWA2SL, ISCSL, IBCSL, INDEX1,	ATVB	5
4INDEX2, I1, K1, L1, ICASE, IRUN, TTM, NDUML, NDUMMY, WGHT, VOL, TIME, IBREAK,	ATVB	6
5WT1MAX, WT2MAX, ICBRTV, INBRTV, BRKTV, NDAMMY, INDEX, ICHANG	ATVB	7
DIMENSION WC(10C0), VC(10C0), N(20), TSC(9, 20), TBC(10, 20), TTV(17, 20)	ATVB	8
1, TSCP(9, 20), TBCP(10, 20), TTVP(17, 20), IDSC(9, 20), IDBC(10, 20), IDTV(ATVB	9
217, 20), INSC(9, 20), INBC(10, 20), INTV(17, 20), AMINSC(9, 20), AMINBC(10	ATVB	10
3, 20), AMINTV(17, 20), AMAXSC(9, 20), AMAXBC(10, 20), AMAXTV(17, 20), NDUMM	ATVB	11
4Y(20), IDBRTV(8, 20), INBRTV(8, 20), BRKTV(8, 20), NDAMMY(20), WGHT(3), VOL	ATVB	12
5(3), TIME(3)	ATVB	13
I1=1	ATVB	14
IF(I-1) 10CC, 10CC, 100	ATVB	15
100 I2=2	ATVB	16
150 IF(TTVP(8, I1)-TTVP(8, I2)) 110, 120, 130	ATVB	17
130 I1=I2	ATVB	18
110 IF(I2-I) 140, 20C0, 20CC	ATVB	19
140 I2=I2+1	ATVB	20
GO TO 150	ATVB	21
120 IF(IDTV(8, I1)-1) 110, 160, 110	ATVB	22
160 A1=TTV(4, I1)+TTV(10, I1)+TTV(11, I1)	ATVB	23
A2=TTV(4, I2)+TTV(10, I2)+TTV(11, I2)	ATVB	24
IF((AMAXTV(6, I1)/A1)-(AMAXTV(6, I2)/A2)) 130, 111, 110	ATVB	25
111 IF((AMAXTV(7, I1)/A1)-(AMAXTV(7, I2)/A2)) 130, 112, 110	ATVB	26
112 IF(AMAXTV(6, I1)-AMAXTV(6, I2)) 130, 113, 110	ATVB	27
113 IF(AMAXTV(7, I1)-AMAXTV(7, I2)) 130, 114, 110	ATVB	28
114 IF(A1-A2) 110, 110, 130	ATVB	29
20C0 IF(INTV(14, I1)) 2010, 20C2C, 2010	ATVB	30
2010 IDTV(8, I1)=0	ATVB	31
TTVP(8, I1)=10.**70	ATVB	32
I1=1	ATVB	33
GO TO 100	ATVB	34
2020 CONTINUE	ATVB	35
GO TO(10C1, 10C2, 10C3, 10C4), IWA2SL	ATVB	36

1001	CONTINUE	ATVB	37
	CALL BSLTVA	ATVB	38
	CONTINUE	ATVB	39
	GO TO 1000	ATVB	40
1002	CONTINUE	ATVB	41
	CALL BSLTVB	ATVB	42
	CONTINUE	ATVB	43
	GO TO 1000	ATVB	44
1003	CONTINUE	ATVB	45
	CALL BSLTVC	ATVB	46
	CONTINUE	ATVB	47
	GO TO 1000	ATVB	48
1004	CONTINUE	ATVB	49
	CALL BSLTVD	ATVB	50
	CONTINUE	ATVB	51
	GO TO 1000	ATVB	52
1000	CONTINUE	ATVB	53
	RETURN	ATVB	54
	END	ATVB	55

SUBROUTINE ASLTVC	ATVC	1
COMMON NCASES,NFUNS,I,K,L,N,WC,VC,TAM,T1,T2,TSC,TBC,TTV,TAMP,T1P,	ATVC	2
1T2P,TSCP,TRCP,TTVP,IDMA,ID1,ID2,IDSC,IDBC,IDTV,INMS,IN1,IN2,INSC,	ATVC	3
2INBC,INTV,AMINM,AMIN1,AMIN2,AMINSC,AMINBC,AMINTV,AMAXM,AMAX1,AMAX2	ATVC	4
3,AMAXSC,AMAXBC,AMAXTV,ISUD,IBUD,IWA1SL,IWA2SL,ISCSL,IBCSL,INDEX1,	ATVC	5
4INDEX2,I1,K1,L1,ICASE,IRUN,TTM,NDUML,NDUMMY,WGHT,VOL,TIME,IBREAK,	ATVC	6
5WT1MAX,WT2MAX,ICBRTV,INBRTV,BRKTV,NDAMMY,INDEX,ICHANG	ATVC	7
DIMENSION WC(1000),VC(1000),N(20),TSC(9,20),TBC(10,20),TTV(17,20)	ATVC	8
1,TSCP(9,20),TBCP(10,20),TTVP(17,20),IDSC(9,20),IDBC(10,20),IDTV(ATVC	9
217,20),INSC(9,20),INBC(10,20),INTV(17,20),AMINSC(9,20),AMINBC(10	ATVC	10
3,20),AMINTV(17,20),AMAXSC(9,20),AMAXBC(10,20),AMAXTV(17,20),NDUMM	ATVC	11
4Y(20),IDBRTV(8,20),INBRTV(8,20),BRKTV(8,20),NDAMMY(20),WGHT(3),VOL	ATVC	12
5(3),TIME(3)	ATVC	13
I1=1	ATVC	14
IF(I-1) 10CC,10CC,100	ATVC	15
100 I2=2	ATVC	16
150 IF(TTVP(8,I1)-TTVP(8,I2)) 110,120,130	ATVC	17
130 I1=I2	ATVC	18
110 IF(I2-I) 140,20CC,20CC	ATVC	19
140 I2=I2+1	ATVC	20
GC TC 150	ATVC	21
120 IF(IDTV(8,I1)-1) 110,160,110	ATVC	22
160 A1=TTV(4,I1)+TTV(10,I1)+TTV(11,I1)	ATVC	23
A2=TTV(4,I2)+TTV(10,I2)+TTV(11,I2)	ATVC	24
IF((AMAXTV(7,I1)/A1)-(AMAXTV(7,I2)/A2)) 130,111,110	ATVC	25
111 IF((AMAXTV(6,I1)/A1)-(AMAXTV(6,I2)/A2)) 130,112,110	ATVC	26
112 IF(AMAXTV(7,I1)-AMAXTV(7,I2)) 130,113,110	ATVC	27
113 IF(AMAXTV(6,I1)-AMAXTV(6,I2)) 130,114,110	ATVC	28
114 IF(A1-A2) 110,115,130	ATVC	29
115 IA1=TTVP(7,I1)/TTV(6,I1)	ATVC	30
IA2=TTVP(7,I2)/TTV(6,I2)	ATVC	31
IF(IA1-IA2) 130,110,110	ATVC	32
2000 IF(INTV(14,I1)) 2010,2020,2010	ATVC	33
2010 ICTV(8,I1)=0	ATVC	34
TTVP(8,I1)=10.**70	ATVC	35
I1=1	ATVC	36

```

GO TO 100
2020 CONTINUE
GO TO(1001,1002,1003,1004),IWA2SL
1001 CONTINUE
CALL BSLTVA
CONTINUE
GO TO 1000
1002 CONTINUE
CALL BSLTVB
CONTINUE
GO TO 1000
1003 CONTINUE
CALL BSLTVC
CONTINUE
GO TO 1000
1004 CONTINUE
CALL BSLTVD
CONTINUE
GO TO 1000
1000 CONTINUE
RETURN
END

```

```

ATVC 37
ATVC 38
ATVC 39
ATVC 40
ATVC 41
ATVC 42
ATVC 43
ATVC 44
ATVC 45
ATVC 46
ATVC 47
ATVC 48
ATVC 49
ATVC 50
ATVC 51
ATVC 52
ATVC 53
ATVC 54
ATVC 55
ATVC 56
ATVC 57
ATVC 58

```

	SUBROUTINE ASLTVD	ATVD	1
	COMMON NCASES, NRUNS, I, K, L, N, WC, VC, TAM, T1, T2, TSC, TBC, TTV, TAMP, T1P,	ATVD	2
	1 T2P, TSCP, TBCP, TTVP, IDMA, ID1, ID2, IDSC, IDBC, IDTV, INMS, IN1, IN2, INSC,	ATVD	3
	2 INBC, INTV, AMINM, AMIN1, AMIN2, AMINSC, AMINBC, AMINTV, AMAXM, AMAX1, AMAX2	ATVD	4
	3, AMAXSC, AMAXRC, AMAXTV, ISUD, IBUD, IWA1SL, IWA2SL, ISCSL, IBCSL, INDEX1,	ATVD	5
	4 INDEX2, I1, K1, L1, ICASE, IRUN, TTM, NDUML, NDUMMY, WGHT, VOL, TIME, IBREAK,	ATVD	6
	5 WT1MAX, WT2MAX, IDBRTV, INBRTV, BRKTV, NDAMMY, INDEX, ICHANG	ATVD	7
	DIMENSION WC(1000), VC(1000), N(20), TSC(9,20), TBC(10,20), TTV(17,20)	ATVD	8
	1, TSCP(9,20), TBCP(10,20), TTVP(17,20), IDSC(9,20), IDBC(10,20), IDTV(ATVD	9
	217,20), INSC(9,20), INBC(10,20), INTV(17,20), AMINSC(9,20), AMINBC(10	ATVD	10
	3,20), AMINTV(17,20), AMAXSC(9,20), AMAXBC(10,20), AMAXTV(17,20), NDUM	ATVD	11
	4Y(20), IDBRTV(8,20), INBRTV(8,20), BRKTV(8,20), NDAMMY(20), WGHT(3),	ATVD	12
	5(3), TIME(3)	ATVD	13
	I1=1	ATVD	14
	IF(I-1) 1000,1000,100	ATVD	15
100	I2=2	ATVD	16
150	IF(TTVP(8,I1)-TTVP(8,I2)) 110,120,130	ATVD	17
130	I1=I2	ATVD	18
110	IF(I2-I) 140,2000,2000	ATVD	19
140	I2=I2+1	ATVD	20
	GO TO 150	ATVD	21
120	IF(IDTV(8,I1)-1) 110,160,110	ATVD	22
160	A1=TTV(4,I1)+TTV(10,I1)+TTV(11,I1)	ATVD	23
	A2=TTV(4,I2)+TTV(10,I2)+TTV(11,I2)	ATVD	24
	IF((AMAXTV(6,I1)/A1)-(AMAXTV(6,I2)/A2)) 130,111,110	ATVD	25
111	IF((AMAXTV(7,I1)/A1)-(AMAXTV(7,I2)/A2)) 130,112,110	ATVD	26
112	IF(AMAXTV(6,I1)-AMAXTV(6,I2)) 130,113,110	ATVD	27
113	IF(AMAXTV(7,I1)-AMAXTV(7,I2)) 130,114,110	ATVD	28
114	IF(A1-A2) 110,115,130	ATVD	29
115	IA1=TTVP(7,I1)/TTV(6,I1)	ATVD	30
	IA2=TTVP(7,I2)/TTV(6,I2)	ATVD	31
	IF(IA1-IA2) 130,110,110	ATVD	32
2000	IF(INTV(14,I1)) 2010,2020,2010	ATVD	33
2010	IDTV(8,I1)=0	ATVD	34
	TTVP(8,I1)=10.**70	ATVD	35
	I1=1	ATVD	36

	GO TO 100	ATVD 37
2020	CONTINUE	ATVD 38
	GO TO(1001,1002,1003,1004),IWA2SL	ATVD 39
1001	CONTINUE	ATVD 40
	CALL BSLTVA	ATVD 41
	CONTINUE	ATVD 42
	GO TO 1000	ATVD 43
1002	CONTINUE	ATVD 44
	CALL BSLTVB	ATVD 45
	CONTINUE	ATVD 46
	GO TO 1000	ATVD 47
1003	CONTINUE	ATVD 48
	CALL BSLTVC	ATVD 49
	CONTINUE	ATVD 50
	GO TO 1000	ATVD 51
1004	CONTINUE	ATVD 52
	CALL BSLTVD	ATVD 53
	CONTINUE	ATVD 54
	GO TO 1000	ATVD 55
1000	CONTINUE	ATVD 56
	RETURN	ATVD 57
	END	ATVD 58

SUBROUTINE ASLTV	ATVE	1
COMMON NCASES, NRUNS, I, K, L, N, WC, VC, TAM, T1, T2, TSC, TBC, TTV, TAMP, TIP,	ATVE	2
1 T2P, TSCP, TRCP, TTVP, IDMA, ID1, ID2, IDSC, IDBC, IDTV, INMS, IN1, IN2, INSC,	ATVE	3
2 INBC, INTV, AMINM, AMIN1, AMIN2, AMINSC, AMINRC, AMINTV, AMAXM, AMAX1, AMAX2	ATVE	4
3, AMAXSC, AMAXBC, AMAXTV, ISUD, IBUD, IWA1SL, IWA2SL, ISCSL, IBCSL, INDEX1,	ATVE	5
4 INDEX2, I1, K1, L1, ICASE, IRUN, TTM, NDUML, NDUMMY, WGHT, VOL, TIME, IBREAK,	ATVE	6
5 WT1MAX, WT2MAX, IDBRTV, INBRTV, BRKTV, NDAMMY, INDEX, ICHANG	ATVE	7
DIMENSION WC(1000), VC(1000), N(20), TSC(9, 20), TBC(10, 20), TTV(17, 20)	ATVE	8
1, TSCP(9, 20), TRCP(10, 20), TTVP(17, 20), IDSC(9, 20), IDBC(10, 20), IDTV(ATVE	9
2 17, 20), INSC(9, 20), INBC(10, 20), INTV(17, 20), AMINSC(9, 20), AMINBC(10	ATVE	10
3, 20), AMINTV(17, 20), AMAXSC(9, 20), AMAXBC(10, 20), AMAXTV(17, 20), NDUMM	ATVE	11
4 Y(20), IDBRTV(8, 20), INBRTV(8, 20), BRKTV(8, 20), NDAMMY(20), WGHT(3), VOL	ATVE	12
5(3), TIME(3)	ATVE	13
I1=1	ATVE	14
IF(I-1) 1000, 1000, 100	ATVE	15
100 I2=2	ATVE	16
150 IF(TTVP(8, I1)-TSCP(6, K1)) 4300, 4300, 4310	ATVE	17
4310 I1=I2	ATVE	18
110 IF(I2-I) 140, 2000, 2000	ATVE	19
140 I2=I2+1	ATVE	20
GO TO 150	ATVE	21
4300 IF(TTVP(8, I2)-TSCP(6, K1)) 4320, 4320, 110	ATVE	22
4320 IDEV1=IDSC(6, K1)	ATVE	23
AW1=0.	ATVE	24
AV1=0.	ATVE	25
4050 AW1=AW1+WC(IDEV1)	ATVE	26
AV1=AV1+VC(IDEV1)	ATVE	27
IF(AMAXTV(6, I1)-AW1) 4010, 4020, 4020	ATVE	28
4010 AW1=AW1-WC(IDEV1)	ATVE	29
AV1=AV1-VC(IDEV1)	ATVE	30
4030 WRAT1=AW1/AMAXTV(6, I1)	ATVE	31
VRAT1=AV1/AMAXTV(7, I1)	ATVE	32
RATIO1=WRAT1+VRAT1	ATVE	33
GO TO 4100	ATVE	34
4020 IF(AMAXTV(7, I1)-AV1) 4010, 4040, 4040	ATVE	35
4040 IDEV1=IDEV1-1	ATVE	36

IF(IDEV1-N(K1)) 4030,4050,4050	ATVE 37
4100 IDEV2=IDSC(6,K1)	ATVE 38
AW2=0.	ATVE 39
AV2=0.	ATVE 40
4150 AW2=AW2+WC(IDEV2)	ATVE 41
AV2=AV2+VC(IDEV2)	ATVE 42
IF(AMAXTV(6,I2)-AW2) 4110,4120,4120	ATVE 43
4110 AW2=AW2-WC(IDEV2)	ATVE 44
AV2=AV2-VC(IDEV2)	ATVE 45
4130 WRAT2=AW2/AMAXTV(6,I2)	ATVE 46
VRAT2=AV2/AMAXTV(7,I2)	ATVE 47
RATIO2=WRAT2+VRAT2	ATVE 48
GO TO 4200	ATVE 49
4120 IF(AMAXTV(7,I2)-AV2) 4110,4140,4140	ATVE 50
4140 IDEV2=IDEV2-1	ATVE 51
IF(IDEV2-N(K1)) 4130,4150,4150	ATVE 52
4200 IF(RATIO1-RATIO2) 4310,110,110	ATVE 53
2000 IF(INTV(14,I1)) 2010,1000,2010	ATVE 54
2010 IDTV(8,I1)=0	ATVE 55
TTVP(8,I1)=10.**70	ATVE 56
I1=1	ATVE 57
GO TO 100	ATVE 58
1000 CONTINUE	ATVE 59
RETURN	ATVE 60
END	ATVE 61

SUBROUTINE BSLTVA	BTVA	1
COMMON NCASES, NRUNS, I, K, L, N, WC, VC, TAM, T1, T2, TSC, TBC, TTV, TAMP, T1P,	BTVA	2
1 T2P, TSCP, TBCP, TTVP, IDMA, ID1, ID2, IDSC, IDBC, IDTV, INMS, IN1, IN2, INSC,	BTVA	3
2 INBC, INTV, AMINM, AMIN1, AMIN2, AMINSC, AMINBC, AMINTV, AMAXM, AMAX1, AMAX2	BTVA	4
3, AMAXSC, AMAXBC, AMAXTV, ISUD, IRUD, IWA1SL, IWA2SL, ISCSL, IBCSL, INDEX1,	BTVA	5
4 INDEX2, I1, K1, L1, ICASE, IRUN, TTM, NDUML, NDUMMY, WGHT, VOL, TIME, IBREAK,	BTVA	6
5 WT1MAX, WT2MAX, IDBRTV, INBRTV, BRKTV, NDAMMY, INDEX, ICHANG	BTVA	7
DIMENSION WC(1000), VC(1000), N(20), TSC(9, 20), TBC(10, 20), TTV(17, 20)	BTVA	8
1, TSCP(9, 20), TBCP(10, 20), TTVP(17, 20), IDSC(9, 20), IDBC(10, 20), IDTV	BTVA	9
2(17, 20), INSC(9, 20), INBC(10, 20), INTV(17, 20), AMINSC(9, 20), AMINBC	BTVA	10
(10, 20), AMINTV(17, 20), AMAXSC(9, 20), AMAXBC(10, 20), AMAXTV(17, 20),	BTVA	11
NDUMMB	BTVA	12
4Y(20), IDBRTV(8, 20), INBRTV(8, 20), BRKTV(8, 20), NDAMMY(20), WGHT(3),	BTVA	13
VOL	BTVA	14
5(3), TIME(3)	BTVA	15
I2=1	BTVA	16
240 IF(TTVP(8, I1)-TTVP(14, I2)) 210, 210, 220	BTVA	17
210 IF(I2-I) 230, 1000, 1000	BTVA	18
230 I2=I2+1	BTVA	19
GO TO 240	BTVA	20
220 I1=I2	BTVA	21
260 IF(I2-I) 250, 1000, 1000	BTVA	22
250 I2=I2+1	BTVA	23
IF(TTVP(14, I1)-TTVP(14, I2)) 260, 270, 220	BTVA	24
270 A1=TTV(13, I1)+TTV(15, I1)+TTV(16, I1)	BTVA	25
A2=TTV(13, I2)+TTV(15, I2)+TTV(16, I2)	BTVA	26
IF((AMAXTV(7, I1)/A1)-(AMAXTV(7, I2)/A2)) 220, 271, 260	BTVA	27
271 IF((AMAXTV(6, I1)/A1)-(AMAXTV(6, I2)/A2)) 220, 272, 260	BTVA	28
272 IF(AMAXTV(7, I1)-AMAXTV(7, I2)) 220, 273, 260	BTVA	29
273 IF(AMAXTV(6, I1)-AMAXTV(6, I2)) 220, 274, 260	BTVA	30
274 IF((AMINTV(7, I1)/A1)-(AMINTV(7, I2)/A2)) 220, 275, 260	BTVA	31
275 IF((AMINTV(6, I1)/A1)-(AMINTV(6, I2)/A2)) 220, 276, 260	BTVA	32
276 IF(AMINTV(7, I1)-AMINTV(7, I2)) 220, 277, 260	BTVA	33
277 IF(AMINTV(6, I1)-AMINTV(6, I2)) 220, 278, 260	BTVA	34
278 IF(A1-A2) 260, 260, 220	BTVA	35
1000 CONTINUE	BTVA	36
RETURN	BTVA	
END	BTVA	

SUBROUTINE BSLTVB		BTVB	1
COMMON NCASES,NRUNS,I,K,L,N,WC,VC,TAM,T1,T2,TSC,TBC,TTV,TAMP,T1P,		BTVB	2
1T2P,TSCP,TBCP,TTVP,IDMA,ID1,ID2,IDSC,IDBC,IDTV,INMS,IN1,IN2,INSC,		BTVB	3
2INBC,INTV,AMINM,AMIN1,AMIN2,AMINSC,AMINBC,AMINTV,AMAXM,AMAX1,AMAX2		BTVB	4
3,AMAXSC,AMAXBC,AMAXTV,ISUD,IBUD,IWA1SL,IWA2SL,ISCSL,IBCSL,INDEX1,		BTVB	5
4INDEX2,I1,K1,L1,ICASE,IRUN,TTM,NDUML,NDUMMY,WGHT,VOL,TIME,IBREAK,		BTVB	6
5WT1MAX,WT2MAX,IDBRTV,INBRTV,BRKTV,NDAMMY,INDEX,ICHANG		BTVB	7
DIMENSION WC(1000),VC(1000),N(20),TSC(9,20),TBC(10,20),TTV(17,20)		BTVB	8
1,TSCP(9,20),TBCP(10,20),TTVP(17,20),IDSC(9,20),IDBC(10,20),IDTV(BTVB	9
217,20),INSC(9,20),INBC(10,20),INTV(17,20),AMINSC(9,20),AMINBC(10		BTVB	10
3,20),AMINTV(17,20),AMAXSC(9,20),AMAXBC(10,20),AMAXTV(17,20),NDUMM		BTVB	11
4Y(20),IDBRTV(8,20),INBRTV(8,20),BRKTV(8,20),NDAMMY(20),WGHT(3),VOL		BTVB	12
5(3),TIME(3)		BTVB	13
I2=1		BTVB	14
240 IF(TTVP(8,I1)-TTVP(14,I2)) 210,210,220		BTVB	15
210 IF(I2-I) 230,1000,1000		BTVB	16
230 I2=I2+1		BTVB	17
GO TO 240		BTVB	18
220 I1=I2		BTVB	19
260 IF(I2-I) 250,1000,1000		BTVB	20
250 I2=I2+1		BTVB	21
IF(TTVP(14,I1)-TTVP(14,I2)) 260,270,220		BTVB	22
270 A1=TTV(13,I1)+TTV(15,I1)+TTV(16,I1)		BTVB	23
A2=TTV(13,I2)+TTV(15,I2)+TTV(16,I2)		BTVB	24
IF((AMAXTV(6,I1)/A1)-(AMAXTV(6,I2)/A2)) 220,271,260		BTVB	25
271 IF((AMAXTV(7,I1)/A1)-(AMAXTV(7,I2)/A2)) 220,272,260		BTVB	26
272 IF(AMAXTV(6,I1)-AMAXTV(6,I2)) 220,273,260		BTVB	27
273 IF(AMAXTV(7,I1)-AMAXTV(7,I2)) 220,274,260		BTVB	28
274 IF((AMINTV(6,I1)/A1)-(AMINTV(6,I2)/A2)) 220,275,260		BTVB	29
275 IF((AMINTV(7,I1)/A1)-(AMINTV(7,I2)/A2)) 220,276,260		BTVB	30
276 IF(AMINTV(6,I1)-AMINTV(6,I2)) 220,277,260		BTVB	31
277 IF(AMINTV(7,I1)-AMINTV(7,I2)) 220,278,260		BTVB	32
278 IF(A1-A2) 260,260,220		BTVB	33
1000 CONTINUE		BTVB	34
RETURN		BTVB	35
END		BTVB	36

SUBROUTINE BSLTVC	BTVC	1
COMMON NCASES, NRUNS, I, K, L, N, WC, VC, TAM, T1, T2, TSC, TRC, TTV, TAMP, T1P,	BTVC	2
1 T2P, TSCP, TBCP, TTVP, IDMA, ID1, ID2, IDSC, IDBC, IDTV, INMS, IN1, IN2, INSC,	BTVC	3
2 INBC, INTV, AMINM, AMIN1, AMIN2, AMINSC, AMINBC, AMINTV, AMAXM, AMAX1, AMAX2	BTVC	4
3, AMAXSC, AMAXBC, AMAXTV, ISUD, IBUD, IWA1SL, IWA2SL, ISCSL, IBCSL, INDEX1,	BTVC	5
4 INDEX2, I1, K1, L1, ICASE, IRUN, TTM, NDUML, NDUMMY, WGHT, VOL, TIME, IBREAK,	BTVC	6
5 WT1MAX, WT2MAX, IDBRTV, INBRTV, BRKTV, NDAMMY, INDEX, ICHANG	BTVC	7
DIMENSION WC(1000), VC(1000), N(20), TSC(9,20), TBC(10,20), TTV(17,20)	BTVC	8
1, TSCP(9,20), TBCP(10,20), TTVP(17,20), IDSC(9,20), IDBC(10,20), IDTV(BTVC	9
217,20), INSC(9,20), INBC(10,20), INTV(17,20), AMINSC(9,20), AMINBC(10	BTVC	10
3,20), AMINTV(17,20), AMAXSC(9,20), AMAXBC(10,20), AMAXTV(17,20), NDUMM	BTVC	11
4Y(20), IDBRTV(8,20), INBRTV(8,20), BRKTV(8,20), NDAMMY(20), WGHT(3), VOL	BTVC	12
5(3), TIME(3)	BTVC	13
I2=1	BTVC	14
240 IF(TTVP(8, I1)-TTVP(14, I2)) 210,210,220	BTVC	15
210 IF(I2-I) 230,1000,1000	BTVC	16
230 I2=I2+1	BTVC	17
GO TO 240	BTVC	18
220 I1=I2	BTVC	19
260 IF(I2-I) 250,1000,1000	BTVC	20
250 I2=I2+1	BTVC	21
IF(TTVP(14, I1)-TTVP(14, I2)) 260,270,220	BTVC	22
270 A1=TTV(13, I1)+TTV(15, I1)+TTV(16, I1)	BTVC	23
A2=TTV(13, I2)+TTV(15, I2)+TTV(16, I2)	BTVC	24
IF((AMAXTV(7, I1)/A1)-(AMAXTV(7, I2)/A2)) 220,271,260	BTVC	25
271 IF((AMAXTV(6, I1)/A1)-(AMAXTV(6, I2)/A2)) 220,272,260	BTVC	26
272 IF(AMAXTV(7, I1)-AMAXTV(7, I2)) 220,273,260	BTVC	27
273 IF(AMAXTV(6, I1)-AMAXTV(6, I2)) 220,274,260	BTVC	28
274 IF((AMINTV(7, I1)/A1)-(AMINTV(7, I2)/A2)) 220,275,260	BTVC	29
275 IF((AMINTV(6, I1)/A1)-(AMINTV(6, I2)/A2)) 220,276,260	BTVC	30
276 IF(AMINTV(7, I1)-AMINTV(7, I2)) 220,277,260	BTVC	31
277 IF(AMINTV(6, I1)-AMINTV(6, I2)) 220,278,260	BTVC	32
278 IF(A1-A2) 260,279,220	BTVC	33
279 IA1=TTVP(7, I1)/TTV(6, I1)	BTVC	34
IA2=TTVP(7, I2)/TTV(6, I2)	BTVC	35
IF(IA1-IA2) 220,260,260	BTVC	36

1000 CONTINUE
RETURN
END

BTVC 37
BTVC 38
BTVC 39

SUBROUTINE BSLTVD	BTVD	1
COMMON NCASES, NRUNS, I, K, L, N, WC, VC, TAM, T1, T2, TSC, TBC, TTV, TAMP, T1P,	BTVD	2
1 T2P, TSCP, TBCP, TTVP, IDMA, ID1, ID2, IDSC, IDBC, IDTV, INMS, IN1, IN2, INSC,	BTVD	3
2 INBC, INTV, AMINM, AMIN1, AMIN2, AMINSC, AMINBC, AMINTV, AMAXM, AMAX1, AMAX2	BTVD	4
3, AMAXSC, AMAXBC, AMAXTV, ISUD, IBUD, IWA1SL, IWA2SL, ISCSL, IBCSL, INDEX1,	BTVD	5
4 INDEX2, I1, K1, L1, ICASE, IRUN, TTM, NDUML, NDUMMY, WGHT, VOL, TIME, IBREAK,	BTVD	6
5 WT1MAX, WT2MAX, IDBRTV, INBRTV, BRKTV, NDAMMY, INDEX, ICHANG	BTVD	7
DIMENSION WC(1000), VC(1000), N(20), TSC(9,20), TBC(10,20), TTV(17,20)	BTVD	8
1, TSCP(9,20), TBCP(10,20), TTVP(17,20), IDSC(9,20), IDBC(10,20), IDTV(BTVD	9
217,20), INSC(9,20), INBC(10,20), INTV(17,20), AMINSC(9,20), AMINBC(10	BTVD	10
3,20), AMINTV(17,20), AMAXSC(9,20), AMAXBC(10,20), AMAXTV(17,20), NDUMM	BTVD	11
4Y(20), IDBRTV(8,20), INBRTV(8,20), BRKTV(8,20), NDAMMY(20), WGHT(3), VOL	BTVD	12
5(3), TIME(3)	BTVD	13
I2=1	BTVD	14
240 IF(TTVP(8,I1)-TTVP(14,I2)) 210,210,220	BTVD	15
210 IF(I2-I) 230,1000,1000	BTVD	16
230 I2=I2+1	BTVD	17
GO TO 240	BTVD	18
220 I1=I2	BTVD	19
260 IF(I2-I) 250,1000,1000	BTVD	20
250 I2=I2+1	BTVD	21
IF(TTVP(14,I1)-TTVP(14,I2)) 260,270,220	BTVD	22
270 A1=TTV(13,I1)+TTV(15,I1)+TTV(16,I1)	BTVD	23
A2=TTV(13,I2)+TTV(15,I2)+TTV(16,I2)	BTVD	24
IF((AMAXTV(6,I1)/A1)-(AMAXTV(6,I2)/A2)) 220,271,260	BTVD	25
271 IF((AMAXTV(7,I1)/A1)-(AMAXTV(7,I2)/A2)) 220,272,260	BTVD	26
272 IF(AMAXTV(6,I1)-AMAXTV(6,I2)) 220,273,260	BTVD	27
273 IF(AMAXTV(7,I1)-AMAXTV(7,I2)) 220,274,260	BTVD	28
274 IF((AMINTV(6,I1)/A1)-(AMINTV(6,I2)/A2)) 220,275,260	BTVD	29
275 IF((AMINTV(7,I1)/A1)-(AMINTV(7,I2)/A2)) 220,276,260	BTVD	30
276 IF(AMINTV(6,I1)-AMINTV(6,I2)) 220,277,260	BTVD	31
277 IF(AMINTV(7,I1)-AMINTV(7,I2)) 220,278,260	BTVD	32
278 IF(A1-A2) 260,279,220	BTVD	33
279 IA1=TTVP(7,I1)/TTV(6,I1)	BTVD	34
IA2=TTVP(7,I2)/TTV(6,I2)	BTVD	35
IF(IA1-IA2) 220,260,260	BTVD	36

1000 CONTINUE
RETURN
END

BTVD 37
BTVD 38
BTVD 39

```

SUBROUTINE SLSCA                                SSSA 1
COMMON NCASES,NRUNS,I,K,L,N,WC,VC,TAM,T1,T2,TSC,TBC,TTV,TAMP,TIP, SSSA 2
1T2P,TSCP,TBCP,TTVP,IDMA,ID1,ID2,IDSC,IDBC,IDTV,INMS,IN1,IN2,INSC, SSSA 3
2INBC,INTV,AMINM,AMIN1,AMIN2,AMINSC,AMINBC,AMINTV,AMAXM,AMAX1,AMAX2SSCA 4
3,AMAXSC,AMAXBC,AMAXTV,ISUD,IBUD,IWA1SL,IWA2SL,ISCSL,IRCSL,INDEX1, SSSA 5
4INDEX2,I1,K1,L1,ICASE,IRUN,TTM,NDUML,NDUMMY,WGHT,VOL,TIME,IBREAK, SSSA 6
5WT1MAX,WT2MAX,IDBRTV,INBRTV,BRKTV,NDAMMY,INDEX,ICHANG          SSSA 7
DIMENSION WC(1000),VC(1000),N(20),TSC( 9,20),TBC(10,20),TTV(17,20)SSCA 8
1,TSCP( 9,20),TBCP(10,20),TTVP(17,20),IDSC( 9,20),IDBC(10,20),IDTV(SSCA 9
217,20),INSC( 9,20),INBC(10,20),INTV(17,20),AMINSC( 9,20),AMINBC(10SSCA 10
3,20),AMINTV(17,20),AMAXSC( 9,20),AMAXBC(10,20),AMAXTV(17,20),NDUMMSSCA 11
4Y(20),IDBRTV(8,20),INBRTV(8,20),BRKTV(8,20),NDAMMY(20),WGHT(3),VOLSSCA 12
5(3),TIME(3)                                                    SSSA 13
3000 FORMAT(1H1,'THE SELECTION OF T.V. NO. ',I2,' FROM W.A. 1 MADE AT 'SSCA 14
1,F8.1,' UNITS OF TIME'/' AFTER THE START OF THE MISSION IS FORFEITSSCA 15
2ED BECAUSE THERE IS NO SHIP'/' UNLOADING FACILITY AVAILABLE TO RECSSCA 16
3EIVE IT.'/' SHIP UNLOADING FACILITY NO. ',I2,' IS THE FIRST ONE TOSSCA 17
4 BECOME AVAILABLE AT '/1H ,F8.1,' UNITS OF TIME AFTER THE START OFSSCA 18
5 THE MISSION.'/' THE DEPARTURE TIME OF ALL TRANSFER VEHICLES IN W.SSSCA 19
6A. 1 THAT COULD DEPART'/' BEFORE THE ABOVE MENTIONED SHIP UNLOADINSSCA 20
7G FACILITY BECAME AVAILABLE IS'/' SET EQUAL TO ',F8.1,' UNITS OF TSSCA 21
8IME.')
```

```

SSCA 22
3100 FORMAT(1H1,'T.V. AND SHIP UNLOADING FACILITY SELECTION.'/'/' T.V. NSSCA 23
10. ',I2,' AND SHIP UNLOADING FACILITY NO. ',I2,' ARE SELECTED AT'/'SSCA 24
21H ,F8.1,' AND ',F8.1,' UNITS OF TIME AFTER THE START OF THE MISSISSCA 25
30N'/' RESPECTIVELY.')
```

```

SSCA 26
IF(INDEX1) 100,100,1000          SSSA 27
100 K1=1                          SSSA 28
IF(K-1) 1010,1010,110          SSSA 29
110 IF(INSC(6,K1)) 120,130,120  SSSA 30
120 K1=K1+1                      SSSA 31
GO TO 110                        SSSA 32
130 IF(K1-K) 140,1010,1010     SSSA 33
140 K2=K1+1                      SSSA 34
151 IF(INSC(6,K2))150,142,150  SSSA 35
150 IF(K2-K) 141,1010,1010     SSSA 36
```

141	K2=K2+1	SSCA	37
	GO TO 151	SSCA	38
142	IF(TSCP(6,K1)-TSCP(6,K2)) 150,160,170	SSCA	39
170	K1=K2	SSCA	40
	GO TO 150	SSCA	41
160	IF(IDSC(6,K1)-N(K1)-IDSC(6,K2)+N(K2)) 170,180,150	SSCA	42
180	IF(AMAXSC(6,K1)-AMAXSC(6,K2)) 150,190,170	SSCA	43
190	A1=TSC(2,K1)+TSC(3,K1)+TSC(4,K1)+TSC(5,K1)+TSC(7,K1)	SSCA	44
	A2=TSC(2,K2)+TSC(3,K2)+TSC(4,K2)+TSC(5,K2)+TSC(7,K2)	SSCA	45
	IF(A1-A2) 150,150,170	SSCA	46
1010	IF(INDEX1) 1000,195,1000	SSCA	47
195	DO 196 II=1,I	SSCA	48
	TTVP(6,II)=0.	SSCA	49
196	CONTINUE	SSCA	50
1000	IF(TSCP(6,K1)-TTVP(8,I1)) 200,200,210	SSCA	51
200	TTV(3,I1)=0.	SSCA	52
	WRITE(6,3100) I1,K1,TTVP(8,I1),TSCP(6,K1)	SSCA	53
	TTVP(8,I1)=10.**70	SSCA	54
	IDTV(8,I1)=2	SSCA	55
	IDTV(14,I1)=IDTV(14,I1)+1	SSCA	56
	AMINTV(6,I1)=0.	SSCA	57
	AMINTV(7,I1)=0.	SSCA	58
	INDEX1=0	SSCA	59
	GO TO 2000	SSCA	60
210	CONTINUE	SSCA	61
	WRITE(6,3000) I1,TTVP(8,I1),K1,TSCP(6,K1),TSCP(6,K1)	SSCA	62
	I1=1	SSCA	63
220	IF(IDTV(8,I1)-1) 240,230,240	SSCA	64
240	IF(I1-I) 250,260,260	SSCA	65
250	I1=I1+1	SSCA	66
	GO TO 220	SSCA	67
230	TTV(3,I1)=TSCP(6,K1)-TTVP(8,I1)	SSCA	68
	IF(TTV(3,I1)) 240,240,241	SSCA	69
241	TTVP(6,I1)=TTV(3,I1)	SSCA	70
	AMAXTV(8,I1)=TSCP(6,K1)	SSCA	71
	TTVP(8,I1)=AMAXTV(8,I1)	SSCA	72

```
GO TO 240
260 INDEX1=1
2000 CONTINUE
RETURN
END
```

```
SSCA 73
SSCA 74
SSCA 75
SSCA 76
SSCA 77
```

```

SUBROUTINE SLSCR                                SSCR  1
COMMON NCASES, NRUNS, I, K, L, N, WC, VC, TAM, T1, T2, TSC, TBC, TTV, TAMP, TIP, SSCR  2
1T2P, TSCP, TBCP, TTVP, IDMA, ID1, ID2, IDSC, IDBC, IDTV, INMS, IN1, IN2, INSC, SSCR  3
2INBC, INTV, AMINM, AMIN1, AMIN2, AMINSC, AMINBC, AMINTV, AMAXM, AMAX1, AMAX2 SSCR  4
3, AMAXSC, AMAXBC, AMAXTV, ISUD, IBUD, IWA1SL, IWA2SL, ISCSL, IBCSL, INDEX1, SSCR  5
4INDEX2, I1, K1, L1, ICASE, IRUN, TTM, NDUML, NDUMMY, WGHT, VOL, TIME, IBREAK, SSCR  6
5WT1MAX, WT2MAX, IDBRTV, INBRTV, BRKTV, NDAMMY, INDEX, ICHANG SSCR  7
DIMENSION WC(1000), VC(1000), N(20), TSC( 9,20), TBC(10,20), TTV(17,20) SSCR  8
1, TSCP( 9,20), TBCP(10,20), TTVP(17,20), IDSC( 9,20), IDBC(10,20), IDTV( SSCR  9
217,20), INSC( 9,20), INBC(10,20), INTV(17,20), AMINSC( 9,20), AMINBC(10 SSCR 10
3,20), AMINTV(17,20), AMAXSC( 9,20), AMAXBC(10,20), AMAXTV(17,20), NDUMM SSCR 11
4Y(20), IDBRTV(8,20), INBRTV(8,20), BRKTV(8,20), NDAMMY(20), WGHT(3), VOL SSCR 12
5(3), TIME(3) SSCR 13
3000 FORMAT(1H1, 'THE SELECTION OF T.V. NO. ', I2, ' FROM W.A. 1 MADE AT ' SSCR 14
1, F8.1, ' UNITS OF TIME'/' AFTER THE START OF THE MISSION IS FORFEIT SSCR 15
2ED BECAUSE THERE IS NO SHIP'/' UNLOADING FACILITY AVAILABLE TO REC SSCR 16
3EIVE IT.'/' SHIP UNLOADING FACILITY NO. ', I2, ' IS THE FIRST ONE TO SSCR 17
4 BECOME AVAILABLE AT '/1H ,F8.1, ' UNITS OF TIME AFTER THE START OF SSCR 18
5 THE MISSION.'/' THE DEPARTURE TIME OF ALL TRANSFER VEHICLES IN W. SSCR 19
6A. 1 THAT COULD DEPART'/' BEFORE THE ABOVE MENTIONED SHIP UNLOADIN SSCR 20
7G FACILITY BECAME AVAILABLE IS'/' SET EQUAL TO ', F8.1, ' UNITS OF T SSCR 21
8IME.') SSCR 22
3100 FORMAT(1H1, 'T.V. AND SHIP UNLOADING FACILITY SELECTION.'/' T.V. N SSCR 23
10. ', I2, ' AND SHIP U LOADING FACILITY NO. ', I2, ' ARE SELECTED AT'/' SSCR 24
21H ,F8.1, ' UNITS OF TIME AFTER THE START OF THE MISSION.') SSCR 25
3200 FORMAT(1H1, 'THE SELECTION OF SHIP UNLOADING FACILITY NO. ', I2, ' MA SSCR 26
1DE AT ', F8.1, ' UNITS'/' OF TIME AFTER THE START OF THE MISSION IS SSCR 27
2FORFEITED BECAUSE THERE WAS'/' NO T.V. IN W.A. 1 TO BE SERVICED.'/' SSCR 28
3' T.V. NO. ', I2, ' WILL BE THE FIRST ONE TO ARRIVE IN W.A. 1 AT ', F SSCR 29
48.1, ' UNITS'/' OF TIME AFTER THE START OF THE MISSION.'/' ALL SHIP SSCR 30
5 UNLOADING FACILITIES THAT ARE FREE BEFORE THE ARRIVAL OF THE'/' ASSCR 31
6BOVE CITED T.V. IN W.A. 1 BECOME EQUALLY ELIGIBLE FOR SELECTION.') SSCR 32
IF(INDEX1) 100,100,1000 SSCR 33
100 K1=1 SSCR 34
IF(K-1) 1010,1010,110 SSCR 35
110 IF(INSC(6,K1)) 120,130,120 SSCR 36

```

120	K1=K1+1	SSCB	37
	GO TO 110	SSCB	38
130	IF(K1-K) 140,1010,1010	SSCB	39
140	K2=K1+1	SSCB	40
151	IF(INSC(6,K2))150,142,150	SSCB	41
150	IF(K2-K) 141,1010,1010	SSCB	42
141	K2=K2+1	SSCB	43
	GO TO 151	SSCB	44
142	IF(TSCP(6,K1)-TSCP(6,K2))150,160,170	SSCB	45
170	K1=K2	SSCB	46
	GO TO 150	SSCB	47
160	IF(IDSC(6,K1)-N(K1)-IDSC(6,K2)+N(K2)) 170,180,150	SSCB	48
180	IF(TSCP(6,K1)-AMAXSC(6,K1)) 181,183,184	SSCB	49
181	IF(TSCP(6,K2)-AMAXSC(6,K2)) 182,170,170	SSCB	50
182	IF(AMAXSC(6,K1)-AMAXSC(6,K2)) 150,190,170	SSCB	51
183	IF(TSCP(6,K2)-AMAXSC(6,K2)) 150,190,170	SSCB	52
184	IF(TSCP(6,K2)-AMAXSC(6,K2)) 150,150,190	SSCB	53
190	A1=TSC(2,K1)+TSC(3,K1)+TSC(4,K1)+TSC(5,K1)+TSC(7,K1)	SSCB	54
	A2=TSC(2,K2)+TSC(3,K2)+TSC(4,K2)+TSC(5,K2)+TSC(7,K2)	SSCB	55
	IF(A1-A2) 150,150,170	SSCB	56
1010	IF(INDEX1) 1000,195,1000	SSCB	57
195	DO 196 II=1,I	SSCB	58
	TTVP(6,II)=0.	SSCB	59
196	CONTINUE	SSCB	60
1000	IF(TSCP(6,K1)-TTVP(8,I1)) 270,200,210	SSCB	61
200	TTV(3,I1)=0.	SSCB	62
	WRITE(6,3100) I1,K1,TTVP(8,I1)	SSCB	63
	TTVP(8,I1)=10.**70	SSCB	64
	IDTV(8,I1)=2	SSCB	65
	IDTV(14,I1)=IDTV(14,I1)+1	SSCB	66
	AMINTV(6,I1)=0.	SSCB	67
	AMINTV(7,I1)=0.	SSCB	68
	INDEX1=0	SSCB	69
	GO TO 2000	SSCB	70
210	CONTINUE	SSCB	71
	WRITE(6,3000) I1,TTVP(8,I1),K1,TSCP(6,K1),TSCP(6,K1)	SSCB	72

I1=1	SSCB 73
220 IF(IDTV(8,I1)-1) 240,230,240	SSCB 74
240 IF(I1-I) 250,260,260	SSCB 75
250 I1=I1+1	SSCB 76
GO TO 220	SSCB 77
230 TTV(3,I1)=TSCP(6,K1)-TTVP(8,I1)	SSCB 78
IF(TTV(3,I1)) 240,240,241	SSCB 79
241 TTVP(6,I1)=TTV(3,I1)	SSCB 80
AMAXTV(8,I1)=TSCP(6,K1)	SSCB 81
TTVP(8,I1)=AMAXTV(8,I1)	SSCB 82
GO TO 240	SSCB 83
260 INDEX1=1	SSCB 84
GO TO 2000	SSCB 85
270 TTV(3,I1)=0.	SSCB 86
WRITE(6,3200) K1,TSCP(6,K1),I1,TTVP(8,I1)	SSCB 87
K1=1	SSCB 88
280 IF(INSC(6,K1)) 290,300,290	SSCB 89
290 IF(K1-K) 320,310,310	SSCB 90
320 K1=K1+1	SSCB 91
GO TO 280	SSCB 92
300 A1=TSCP(6,K1)-TTVP(8,I1)	SSCB 93
IF(A1) 330,290,290	SSCB 94
330 TSCP(6,K1)=TTVP(8,I1)	SSCB 95
GO TO 290	SSCB 96
310 INDEX1=-1	SSCB 97
2000 CONTINUE	SSCB 98
RETURN	SSCB 99
END	SSCB 100

```

SUBROUTINE SLSCC                                SSSC 1
COMMON NCASES, NRUNS, I, K, L, N, WC, VC, TAM, T1, T2, TSC, TBC, TTV, TAMP, T1P, SSSC 2
1T2P, TSCP, TBCP, TTVP, IDMA, ID1, ID2, IDSC, IDBC, IDTV, INMS, IN1, IN2, INSC, SSSC 3
2INBC, INTV, AMINM, AMIN1, AMIN2, AMINSC, AMINBC, AMINTV, AMAXM, AMAX1, AMAX2SSCC 4
3, AMAXSC, AMAXBC, AMAXTV, ISUD, IBUD, IWA1SL, IWA2SL, ISCSL, IBCSL, INDEX1, SSSC 5
4INDEX2, I1, K1, L1, ICASE, IRUN, TTM, NDUML, NDUMMY, WGHT, VOL, TIME, IBREAK, SSSC 6
5WT1MAX, WT2MAX, IDBRTV, INBRTV, BRKTV, NDAMMY, INDEX, ICHANG SSSC 7
DIMENSION WC(1000), VC(1000), N(20), TSC( 9,20), TBC(10,20), TTV(17,20)SSCC 8
1, TSCP( 9,20), TBCP(10,20), TTVP(17,20), IDSC( 9,20), IDBC(10,20), IDTV(SSCC 9
217,20), INSC( 9,20), INBC(10,20), INTV(17,20), AMINSC( 9,20), AMINBC(10SSCC 10
3,20), AMINTV(17,20), AMAXSC( 9,20), AMAXBC(10,20), AMAXTV(17,20), NDUMMSSCC 11
4Y(20), IDBRTV(8,20), INBRTV(8,20), BRKTV(8,20), NDAMMY(20), WGHT(3), VOLSSCC 12
5(3), TIME(3) SSSC 13
3100 FORMAT(1H1, 'T.V. AND SHIP UNLOADING FACILITY SELECTION.'// ' T.V. NSSCC 14
10. ', I2, ' AND SHIP U LOADING FACILITY NO. ', I2, ' ARE SELECTED AT'//SSCC 15
21H ,F8.1, ' UNITS OF TIME AFTER THE START OF THE MISSION.') SSSC 16
K1=1 SSSC 17
IF(K-1) 1010,1010,110 SSSC 18
110 IF(INSC(6,K1)) 120,130,120 SSSC 19
120 K1=K1+1 SSSC 20
GO TO110 SSSC 21
130 IF(K1-K) 140,1010,1010 SSSC 22
140 K2=K1+1 SSSC 23
151 IF(INSC(6,K2)) 150,142,150 SSSC 24
150 IF (K2-K) 141,1010,1010 SSSC 25
141 K2=K2+1 SSSC 26
GO TO 151 SSSC 27
142 IF(TSCP(6,K1)-TTVP(8,I1)) 4300,4300,4310 SSSC 28
4310 K1=K2 SSSC 29
GO TO 150 SSSC 30
4300 IF(TSCP(6,K2)-TTVP(8,I1)) 4320,4320,150 SSSC 31
4320 IDEV1=IDSC(6,K1) SSSC 32
AW1=0. SSSC 33
AV1=0. SSSC 34
4050 AW1=AW1+WC(IDEV1) SSSC 35
AV1=AV1+VC(IDEV1) SSSC 36

```

IF (AMAXTV(6,I1)-AW1) 4010,4020,4020	SSCC	37
4010 AW1=AW1-WC(IDEV1)	SSCC	38
AV1=AV1-VC(IDEV1)	SSCC	39
4030 WRAT1=AW1/AMAXTV(6,I1)	SSCC	40
VRAT1=AV1/AMAXTV(7,I1)	SSCC	41
RATIO1=WRAT1+VRAT1	SSCC	42
GO TO 4100	SSCC	43
4020 IF (AMAXTV(7,I1)-AV1) 4010,4040,4040	SSCC	44
4040 IDEV1=IDEV1-1	SSCC	45
IF(IDEV1-N(K1)) 4030,4050,4050	SSCC	46
4100 IDEV2=IDSC(6,K2)	SSCC	47
AW2=0.	SSCC	48
AV2=0.	SSCC	49
4150 AW2=AW2+WC(IDEV2)	SSCC	50
AV2=AV2+VC(IDEV2)	SSCC	51
IF(AMAXTV(6,I1)-AW2) 4110,4120,4120	SSCC	52
4110 AW2=AW2-WC(IDEV2)	SSCC	53
AV2=AV2-VC(IDEV2)	SSCC	54
4130 WRAT2=AW2/AMAXTV(6,I1)	SSCC	55
VRAT2=AV2/AMAXTV(7,I1)	SSCC	56
RATIO2=WRAT2+VRAT2	SSCC	57
GO TO 4200	SSCC	58
4120 IF (AMAXTV(7,I1)-AV2) 4110,4140,4140	SSCC	59
4140 IDEV2=IDEV2-1	SSCC	60
IF(IDEV2-N(K2)) 4130,4150,4150	SSCC	61
4200 IF (RATIO1-RATIO2) 4310,150,150	SSCC	62
1010 TTV(3,I1)=0.	SSCC	63
WRITE(6,3100) I1,K1,TTVP(8,I1)	SSCC	64
TTVP(8,I1)=10.**70	SSCC	65
IDTV(8,I1)=2	SSCC	66
IDTV(14,I1)=IDTV(14,I1)+1	SSCC	67
AMINTV(6,I1)=0.	SSCC	68
AMINTV(7,I1)=0.	SSCC	69
INDEX1=0	SSCC	70
RETURN	SSCC	71
END	SSCC	72

```

SUBROUTINE LOAD                                LOAD 1
COMMON NCASES,NRUNS,I,K,L,N,WC,VC,TAM,T1,T2,TSC,TRC,TTV,TAMP,T1P, LOAD 2
1T2P,TSCP,TRCP,TTVP,IDMA,ID1,ID2,IDSC,IDBC,IDTV,INMS,IN1,IN2,INSC, LOAD 3
2INBC,INTV,AMINM,AMIN1,AMIN2,AMINSC,AMINBC,AMINTV,AMAXM,AMAX1,AMAX2LOAD 4
3,AMAXSC,AMAXBC,AMAXTV,ISUD,IBUD,IWA1SL,IWA2SL,TSCSL,IBCSL,INDEX1, LOAD 5
4INDEX2,I1,K1,L1,ICASE,IRUN,TTM,NDUML,NDUMMY,WGHT,VOL,TIME,IBREAK, LOAD 6
5WT1MAX,WT2MAX,IDBRTV,INBRTV,BRKTV,NDAMMY,INDEX,ICHANG          LOAD 7
  DIMENSION WC(1000),VC(1000),N(20),TSC( 9,20),TRC(10,20),TTV(17,20)LOAD 8
  1,TSCP( 9,20),TRCP(10,20),TTVP(17,20),IDSC( 9,20),IDBC(10,20),IDTV(LOAD 9
  217,20),INSC( 9,20),INBC(10,20),INTV(17,20),AMINSC( 9,20),AMINBC(10LOAD 10
  3,20),AMINTV(17,20),AMAXSC( 9,20),AMAXBC(10,20),AMAXTV(17,20),NDUMMLLOAD 11
  4Y(20),IDBRTV(8,20),INBRTV(8,20),BRKTV(8,20),NDAMMY(20),WGHT(3),VOLLOAD 12
  5(3),TIME(3)                                                    LOAD 13
4000 FORMAT(' T.V. NO. ',I2,' DEPARTED W.A. 1 FOR SHIP UNLOADING AREA NLOAD 14
10. ',I2,', 'F8.1/' UNITS OF TIME AFTER THE START OF THE MISSION.')

```

4110	FORMAT(' AND IT IS PROPERLY SECURED IN THE T.V. AFTER',6X,F8.1,1X,LOAD	37
	13A4)	LOAD 38
4120	FORMAT(1H ,///// ' ALL CARGO UNITS ASSOCIATED WITH S.U.F. NO. ',I2,'LOAD	39
	1 HAVE BEEN UNLOADED SO THE'/' OPERATION OF S.U.F. NO. ',I2,' HAS TLOAD	40
	2TERMINATED.'/' THE ABOVE CITED S.U.F. REACHES ITS ORIGINAL POSITIONLOAD	41
	3 ',F8.1,' UNITS OF'/' TIME AFTER THE START OF THE MISSION AND IS PLOAD	42
	4ROPERLY SECURED IN')	LOAD 43
4130	FORMAT(' POSITION ',F8.1,' UNITS OF TIME AFTER THE START OF THE MILOAD	44
	SSION.')	LOAD 45
4140	FORMAT(1H ,///// ' THE UNLOADING OPERATION HAS TO TERMINATE BECAUSE LOAD	46
	1OTHERWISE THE WEIGHT'/' PAYLOAD OF T.V. NO. ',I2,' WILL BE EXCEEDELOAD	47
	2D.')	LOAD 48
4141	FORMAT(1H ,///// ' T.V. USE STRATEGIES ASLTVB AND BSLTVB COME INTO ELOAD	49
	1FFECT.')	LOAD 50
4142	FORMAT(1H ,///// ' T.V. USE STRATEGIES ASLTVD AND BSLTVD COME INTO ELOAD	51
	1FFECT.')	LOAD 52
4150	FORMAT(' IN ADDITION')	LOAD 53
4160	FORMAT(' THE UNLOADING OPERATION HAS TO TERMINATE BECAUSE OTHERWISLOAD	54
	1F THE VOLUME'/' PAYLOAD OF T.V. NO. ',I2,' WILL BE EXCEEDED.')	LOAD 55
4161	FORMAT(1H ,///// ' T.V. USE STRATEGIES ASLTVA AND BSLTVA COME INTO ELOAD	56
	1FFECT.')	LOAD 57
4162	FORMAT(1H ,///// ' T.V. USE STRATEGIES ASLTVG AND BSLTVG COME INTO ELOAD	58
	1FFECT.')	LOAD 59
4170	FORMAT(1H ,///// ' T.V. NO. ',I2,' WAS UNHOOKED AND WAS READY TO STALOAD	60
	1RT FOR W.A. 2 ',F8.1/' UNITS OF TIME AFTER THE START OF THE MISSILOAD	61
	2N')	LOAD 62
4180	FORMAT(' AND AT THE SAME TIME SHIP UNLOADING AREA NO. ',I2,' BECAMLOAD	63
	1E ONCE MORE'/' AVAILABLE.')	LOAD 64
4190	FORMAT(' AND AT THE SAME TIME ALL SHIP UNLOADING AREAS BECAME ONCELOAD	65
	1 MORE AVAILABLE.')	LOAD 66
4200	FORMAT(1H ,///// ' T.V. NO. ',I2,' ARRIVED AT W.A. 2 ',F8.1,' UNITS LOAD	67
	1OF TIME AFTER THE START OF'/' THE MISSION.')	LOAD 68
4001	FORMAT(1H ,/// ' T.V. BREAKDOWN CONSIDERATIONS. '/// ' T.V. NO. ',I2LOAD	69
	1,' IS NOT ALLOWED TO DEPART W.A. 1 AS IT IS CONSIDERED TO BE'/' MALLOAD	70
	2LFUNCTIONING. THE ABOVE CITED T.V. IS CONSIDERED LOST FROM OUR'/'LOAD	71
	3 SYSTEM FOR THIS COMPUTER RUN. IN ADDITION THE ABOVE MENTIONED T.LOAD	72

4V. AND	'/' SHIP UNLOADING FACILITY SELECTION IS FORFEITED.'	LOAD	73
4002	FORMAT(1H ,///' T.V. BREAKDOWN CONSIDERATIONS. '///' T.V. NO. ',I2LOAD		74
	1,' HAS SAFELY DEPARTED W.A. 1.'///)	LOAD	75
4003	FORMAT(1H ,///)	LOAD	76
4011	FORMAT(1H ,///' T.V. BREAKDOWN CONSIDERATIONS. '///' T.V. NO. ',I2LOAD		77
	1,' IS NOT ALLOWED TO REACH THE MOTHER SHIP AS IT IS CONSIDERED	'/' LOAD	78
	2TO BE MALFUNCTIONING. THE ABOVE CITED T.V. IS CONSIDERED LOST FROM	LOAD	79
	3M OUR	'/' SYSTEM FOR THIS COMPUTER RUN. IN ADDITION THE ABOVE MENT	LOAD
	4IONED T.V. AND	'/' SHIP UNLOADING FACILITY SELECTION IS FORFEITED.'	LOAD
	5)	LOAD	82
4012	FORMAT(1H ,///' T.V. BREAKDOWN CONSIDERATIONS. '///' T.V. NO. ',I2LOAD		83
	1,' HAS SAFELY REACHED THE MOTHER SHIP.'///)	LOAD	84
4021	FORMAT(1H ,///' T.V. BREAKDOWN CONSIDERATIONS. '///' T.V. NO. ',I2LOAD		85
	1,' IS NOT ALLOWED TO ENTER W.A. 2 AS IT IS CONSIDERED TO BE	'/' MAL	LOAD
	2FUNCTIONING. THE ABOVE CITED T.V. AND ITS ENTIRE PAYLOAD IS	'/' CO	LOAD
	3NSIDERED LOST FROM OUR SYSTEM FOR THIS COMPUTER RUN.'	LOAD	88
4022	FORMAT(1H ,///' T.V. BREAKDOWN CONSIDERATIONS. '///' T.V. NO. ',I2LOAD		89
	1,' HAS SAFELY ENTERED W.A. 2.')	LOAD	90
	DO 100 JJ=3,4	LOAD	91
	IDD=IDTV(JJ,I1)	LOAD	92
	GO TO (2000,2001),IDD	LOAD	93
2000	TTVP(JJ,I1)=0.	LOAD	94
	GO TO 100	LOAD	95
2001	IND=INTV(JJ,I1)	LOAD	96
	CALL RANDU(IND,IND,TPD)	LOAD	97
	INTV(JJ,I1)=IND	LOAD	98
	TTVP(JJ,I1)=(AMAXTV(JJ,I1)-AMINTV(JJ,I1))*TPD+AMINTV(JJ,I1)-TTV(JJ,I1)	LOAD	99
	1,I1)	LOAD	100
	GO TO 100	LOAD	101
100	CONTINUE	LOAD	102
	IDD=IDBRTV(2,I1)	LOAD	103
	GO TO (207,201),IDD	LOAD	104
201	TTVP(6,I1)=TTVP(6,I1)+TTVP(3,I1)	LOAD	105
	TTVP(6,I1)=TTVP(6,I1)/WT1MAX	LOAD	106
	IF(TTVP(6,I1)-1.) 202,203,203	LOAD	107
202	TTVP(6,I1)=TTVP(6,I1)*BRKTV(2,I1)	LOAD	108

	GO TO 204	LOAD 109
203	TTVP(6,I1)=BRKTV(2,I1)	LOAD 110
204	IND=INBRTV(2,I1)	LOAD 111
	CALL RANDU(IND,IND,TPD)	LOAD 112
	INBRTV(2,I1)=IND	LOAD 113
	IF(TTVP(6,I1)-TPD) 200,200,205	LOAD 114
205	IDTV(14,I1)=IDTV(14,I1)-1	LOAD 115
	IDTV(8,I1)=0	LOAD 116
	IBREAK=IBREAK-1	LOAD 117
	WRITE(6,4001) I1	LOAD 118
	GO TO 206	LOAD 119
200	CONTINUE	LOAD 120
	WRITE(6,4002) I1	LOAD 121
	GO TO 208	LOAD 122
207	CONTINUE	LOAD 123
	WRITE(6,4003)	LOAD 124
208	AMAXTV(8,I1)=AMAXTV(8,I1)+TTV(3,I1)+TTVP(3,I1)	LOAD 125
	WRITE(6,4000) I1,K1,AMAXTV(8,I1)	LOAD 126
	IDD=IDBRTV(3,I1)	LOAD 127
	GO TO (210,211),IDD	LOAD 128
211	IND=INBRTV(3,I1)	LOAD 129
	CALL RANDU(IND,IND,TPD)	LOAD 130
	INBRTV(3,I1)=IND	LOAD 131
	IF(BRKTV(3,I1)-TPD) 213,213,212	LOAD 132
212	IDTV(14,I1)=IDTV(14,I1)-1	LOAD 133
	IDTV(8,I1)=0	LOAD 134
	IBREAK=IBREAK-1	LOAD 135
	WRITE(6,4011) I1	LOAD 136
	GO TO 206	LOAD 137
213	CONTINUE	LOAD 138
	WRITE(6,4012) I1	LOAD 139
	GO TO 214	LOAD 140
210	CONTINUE	LOAD 141
	WRITE(6,4003)	LOAD 142
214	AMAXTV(8,I1)=AMAXTV(8,I1)+TTV(4,I1)+TTVP(4,I1)	LOAD 143
	WRITE(6,4010) I1,K1,AMAXTV(8,I1)	LOAD 144

	TTVP(7,I1)=TTVP(7,I1)-TTV(6,I1)	LOAD 145
	IF(TTVP(7,I1)) 1000,1101,1101	LOAD 146
1000	IDD=IDTV(5,I1)	LOAD 147
	GO TO (2010,2011),IDD	LOAD 148
2010	TTVP(5,I1)=0.	LOAD 149
	GO TO 3010	LOAD 150
2011	IND=IDTV(5,I1)	LOAD 151
	CALL RANDU(IND,IND,TPD)	LOAD 152
	INTV(5,I1)=IND	LOAD 153
	TTVP(5,I1)=(AMAXTV(5,I1)-AMAXTV(5,I1))*TPD+AMINTV(5,I1)-TTV(5,I1)	LOAD 154
	GO TO 3010	LOAD 155
3010	AMAXTV(8,I1)=AMAXTV(8,I1)+TTV(5,I1)+TTVP(5,I1)	LOAD 156
	TTVP(7,I1)=TTV(7,I1)	LOAD 157
	WRITE(6,4020) I1,AMAXTV(8,I1)	LOAD 158
1101	NDUMMY(I1)=IDSC(6,K1)	LOAD 159
	WRITE(6,4030)	LOAD 160
	NTEMP=IDSC(6,K1)	LOAD 161
	AMINTV(6,I1)=AMINTV(6,I1)+WC(NTEMP)	LOAD 162
	AMINTV(7,I1)=AMINTV(7,I1)+VC(NTEMP)	LOAD 163
1100	DO 110 JJ=2,5	LOAD 164
	IDD=IDSC(JJ,K1)	LOAD 165
	GO TO (2020,2021),IDD	LOAD 166
2020	TSCP(JJ,K1)=0.	LOAD 167
	GO TO 110	LOAD 168
2021	IND=INSC(JJ,K1)	LOAD 169
	CALL RANDU(IND,IND,TPD)	LOAD 170
	INSC(JJ,K1)=IND	LOAD 171
	TSCP(JJ,K1)=(AMAXSC(JJ,K1)-AMINSC(JJ,K1))*TPD+AMINSC(JJ,K1)-TSC(JJ,	LOAD 172
	1,K1)	LOAD 173
	GO TO 110	LOAD 174
110	CONTINUE	LOAD 175
	WRITE(6,4040) NTEMP,WC(NTEMP),(WGHT(JJ),JJ=1,3),VC(NTEMP),(VOL(JJ)	LOAD 176
	1, JJ=1,3)	LOAD 177
	AMAXSC(6,K1)=AMAXSC(6,K1)+TSC(2,K1)+TSCP(2,K1)	LOAD 178
	WRITE(6,4050) AMAXSC(6,K1),(TIME(JJ),JJ=1,3)	LOAD 179
	AMAXSC(6,K1)=AMAXSC(6,K1)+TSC(3,K1)+TSCP(3,K1)	LOAD 180

	WRITE(6,4060) AMAXSC(6,K1),(TIME(JJ),JJ=1,3)	LOAD 181
	AMAXSC(6,K1)=AMAXSC(6,K1)+TSC(4,K1)+TSCP(4,K1)	LOAD 182
	WRITE(6,4070) AMAXSC(6,K1),(TIME(JJ),JJ=1,3)	LOAD 183
	AMAXSC(6,K1)=AMAXSC(6,K1)+TSC(5,K1)+TSCP(5,K1)	LOAD 184
	WRITE(6,4080) AMAXSC(6,K1),(TIME(JJ),JJ=1,3)	LOAD 185
	IF(AMAXSC(6,K1)-AMAXTV(8,I1)) 1200,1200,1300	LOAD 186
1200	TTV(8,I1)=0.	LOAD 187
	TSC(6,K1)=AMAXTV(8,I1)-AMAXSC(6,K1)	LOAD 188
	GO TO 1210	LOAD 189
1300	TSC(6,K1)=0.	LOAD 190
	TTV(8,I1)=AMAXSC(6,K1)-AMAXTV(8,I1)	LOAD 191
1210	AMAXSC(6,K1)=AMAXSC(6,K1)+TSC(6,K1)	LOAD 192
	AMAXTV(8,I1)=AMAXSC(6,K1)	LOAD 193
	WRITE(6,4090) AMAXSC(6,K1),(TIME(JJ),JJ=1,3)	LOAD 194
	IDD=IDSC(7,K1)	LOAD 195
	GO TO (2030,2031),IDD	LOAD 196
2030	TSCP(7,K1)=0.	LOAD 197
	GO TO 3030	LOAD 198
2031	IND=INSC(7,K1)	LOAD 199
	CALL RANDU (IND,IND,TPD)	LOAD 200
	INSC(7,K1)=IND	LOAD 201
	TSCP(7,K1)=(AMAXSC(7,K1)-AMINSC(7,K1))*TPD+AMINSC(7,K1)-TSC(7,K1)	LOAD 202
	GO TO 3030	LOAD 203
3030	AMAXSC(6,K1)=AMAXSC(6,K1)+TSC(7,K1)+TSCP(7,K1)	LOAD 204
	AMAXTV(8,I1)=AMAXSC(6,K1)	LOAD 205
	WRITE(6,4100) AMAXSC(6,K1),(TIME(JJ),JJ=1,3)	LOAD 206
	IDSC(6,K1)=IDSC(6,K1)-1	LOAD 207
	IF(IDSC(6,K1)-N(K1)) 1500,1400,1400	LOAD 208
1500	INSC(6,K1)=1	LOAD 209
	DO 120 JJ=8,9	LOAD 210
	IDD=IDSC(JJ,K1)	LOAD 211
	GO TO (2040,2041),IDD	LOAD 212
2040	TSCP(JJ,K1)=0.	LOAD 213
	GO TO 120	LOAD 214
2041	IND=INSC(JJ,K1)	LOAD 215
	CALL RANDU(IND,IND,TPD)	LOAD 216

INSC(JJ,K1)=IND	LOAD 217
TSCP(JJ,K1)=(AMAXSC(JJ,K1)-AMINSC(JJ,K1))*TPD+AMINSC(JJ,K1)-TSC(JJ,1,K1)	LOAD 218
GO TO 120	LOAD 219
120 CONTINUE	LOAD 220
1400 IDD=IDTV(9,I1)	LOAD 221
GO TO (2050,2051),IDD	LOAD 222
2050 TTVP(9,I1)=0.	LOAD 223
GO TO 3050	LOAD 224
2051 IND=INTV(9,I1)	LOAD 225
CALL RANDU(IND,IND,TPD)	LOAD 226
INTV(9,I1)=IND	LOAD 227
TTVP(9,I1)=(AMAXTV(9,I1)-AMINTV(9,I1))*TPD+AMINTV(9,I1)-TTV(9,I1)	LOAD 228
GO TO 3050	LOAD 229
3050 AMAXTV(8,I1)=AMAXTV(8,I1)+TTV(9,I1)+TTVP(9,I1)	LOAD 230
WRITE(6,4110) AMAXTV(8,I1),(TIME(JJ),JJ=1,3)	LOAD 231
IF(IDSC(6,K1)-N(K1)) 1601,1700,1700	LOAD 232
1601 AMAXSC(6,K1)=AMAXSC(6,K1)+TSC(8,K1)+TSCP(8,K1)	LOAD 233
WRITE(6,4120) K1,K1,AMAXSC(6,K1)	LOAD 234
AMAXSC(6,K1)=AMAXSC(6,K1)+TSC(9,K1)+TSCP(9,K1)	LOAD 235
WRITE(6,4130) AMAXSC(6,K1)	LOAD 236
IF(K1-K) 1602,1603,1602	LOAD 237
1602 IDSC(6,K1)=N(K1+1)-1	LOAD 238
NDAMMY(I1)=N(K1)	LOAD 239
GO TO 1600	LOAD 240
1603 IDSC(6,K)=NDUML	LOAD 241
NDAMMY(I1)=N(K)	LOAD 242
GO TO 1600	LOAD 243
1700 NTEMP=IDSC(6,K1)	LOAD 244
AMINTV(6,I1)=AMINTV(6,I1)+WC(NTEMP)	LOAD 245
AMINTV(7,I1)=AMINTV(7,I1)+VC(NTEMP)	LOAD 246
IF(AMAXTV(6,I1)-AMINTV(6,I1)) 1710,1720,1720	LOAD 247
1710 AMINTV(6,I1)=AMINTV(6,I1)-WC(NTEMP)	LOAD 248
WRITE(6,4140) I1	LOAD 249
IF(AMAXTV(7,I1)-AMINTV(7,I1)) 1730,1780,1780	LOAD 250
1780 CONTINUE	LOAD 251
	LOAD 252

GO TO (1740,1791), ICHANG	LOAD 253
1791 CONTINUE	LOAD 254
GO TO (1792,1792,1793,1793,1740,1740,1740,1740), IWA1SL	LOAD 255
1792 IWA1SL=2	LOAD 256
IWA2SL=2	LOAD 257
WRITE(6,4141)	LOAD 258
GO TO 1740	LOAD 259
1793 IWA1SL=4	LOAD 260
IWA2SL=4	LOAD 261
WRITE(6,4142)	LOAD 262
GO TO 1740	LOAD 263
1730 CONTINUE	LOAD 264
WRITE(6,4150)	LOAD 265
1750 CONTINUE	LOAD 266
WRITE(6,4160) I1	LOAD 267
1740 AMINTV(7, I1)=AMINTV(7, I1)-VC(NTEMP)	LOAD 268
NDAMMY(I1)=IDSC(6, K1)+1	LOAD 269
GO TO 1600	LOAD 270
1720 IF(AMAXTV(7, I1)-AMINTV(7, I1)) 1760, 1100, 1100	LOAD 271
1760 AMINTV(6, I1)=AMINTV(6, I1)-WC(NTEMP)	LOAD 272
GO TO (1750,1790), ICHANG	LOAD 273
1790 CONTINUE	LOAD 274
GO TO (1761,1761,1762,1762,1750,1750,1750,1750), IWA1SL	LOAD 275
1761 IWA1SL=1	LOAD 276
IWA2SL=1	LOAD 277
WRITE(6,4161)	LOAD 278
GO TO 1750	LOAD 279
1762 IWA1SL=3	LOAD 280
IWA2SL=3	LOAD 281
WRITE(6,4162)	LOAD 282
GO TO 1750	LOAD 283
1600 IDD=IDTV(10, I1)	LOAD 284
GO TO (2060,2061), IDD	LOAD 285
2060 TTVP(10, I1)=0.	LOAD 286
GO TO 3060	LOAD 287
2061 IND=INTV(10, I1)	LOAD 288

CALL RANDU(IND,IND,TPD)	LOAD 289
INTV(10,I1)=IND	LOAD 290
TTVP(10,I1)=(AMAXTV(10,I1)-AMINTV(10,I1))*TPD+AMINTV(10,I1)-TTV(10,I1)	LOAD 291
1, I1)	LOAD 292
GO TO 3060	LOAD 293
3060 AMAXTV(8,I1)=AMAXTV(8,I1)+TTV(10,I1)+TTVP(10,I1)	LOAD 294
WRITE(6,4170) I1,AMAXTV(8,I1)	LOAD 295
IF(ISUD-1) 1800,1900,1800	LOAD 296
1800 KLOOP=K	LOAD 297
KT=1	LOAD 298
WRITE(6,4190)	LOAD 299
GO TO 1810	LOAD 300
1900 KLOOP=1	LOAD 301
KT=K1	LOAD 302
WRITE(6,4180) K1	LOAD 303
1810 DO 130 KK=1,KLOOP	LOAD 304
TSCP(6,KT)=AMAXTV(8,I1)	LOAD 305
KT=KT+1	LOAD 306
130 CONTINUE	LOAD 307
IDD=IDTV(11,I1)	LOAD 308
GO TO (2070,2071),IDD	LOAD 309
2070 TTVP(11,I1)=0.	LOAD 310
GO TO 3070	LOAD 311
2071 IND=INTV(11,I1)	LOAD 312
CALL RANDU(IND,IND,TPD)	LOAD 313
INTV(11,I1)=IND	LOAD 314
TTVP(11,I1)=(AMAXTV(11,I1)-AMINTV(11,I1))*TPD+AMINTV(11,I1)-TTV(11,I1)	LOAD 315
1, I1)	LOAD 316
GO TO 3070	LOAD 317
3070 IDD=IDBRTV(4,I1)	LOAD 318
GO TO (220,221),IDD	LOAD 319
221 IND=INBRTV(4,I1)	LOAD 320
CALL RANDU(IND,IND,TPD)	LOAD 321
INBRTV(4,I1)=IND	LOAD 322
IF(BRKTV(4,I1)-TPD) 223,223,222	LOAD 323
222 IDTV(14,I1)=IDTV(14,I1)-1	LOAD 324

IDTV(8,I1)=0	LOAD 325
IBREAK=IBREAK-1	LOAD 326
WRITE(6,4021) I1	LOAD 327
GO TO 206	LOAD 328
223 CONTINUE	LOAD 329
WRITE(6,4022) I1	LOAD 330
220 AMAXTV(8,I1)=AMAXTV(8,I1)+TTV(11,I1)+TTVP(11,I1)	LOAD 331
TTVP(14,I1)=AMAXTV(8,I1)	LOAD 332
WRITE(6,4200)I1,AMAXTV(8,I1)	LOAD 333
206 CONTINUE	LOAD 334
RETURN	LOAD 335
END	LOAD 336

SUBROUTINE SLBCA	SBCA	1
COMMON NCASES, NRUNS, I, K, L, N, WC, VC, TAM, T1, T2, TSC, TBC, TTV, TAMP, T1P,	SBCA	2
1T2P, TSCP, TBCP, TTVP, IDMA, ID1, ID2, IDSC, IDBC, IDTV, INMS, IN1, IN2, INSC,	SBCA	3
2INBC, INTV, AMINM, AMIN1, AMIN2, AMINSC, AMINBC, AMINTV, AMAXM, AMAX1, AMAX2	SBCA	4
3, AMAXSC, AMAXBC, AMAXTV, ISUD, IBUD, IWA1SL, IWA2SL, TSCSL, IRCSL, INDEX1,	SBCA	5
4INDEX2, I1, K1, L1, ICASF, IRUN, TTM, NDUML, NDUMMY, WGHT, VOL, TIME, IBREAK,	SBCA	6
5WT1MAX, WT2MAX, IDBRTV, INBRTV, BRKTV, NDAMMY, INDEX, ICHANG	SBCA	7
DIMENSION WC(1000), VC(1000), N(20), TSC(9,20), TBC(10,20), TTV(17,20)	SBCA	8
1, TSCP(9,20), TBCP(10,20), TTVP(17,20), IDSC(9,20), IDBC(10,20), IDTV(SBCA	SBCA	9
217,20), INSC(9,20), INBC(10,20), INTV(17,20), AMINSC(9,20), AMINBC(10SBCA	SBCA	10
3,20), AMINTV(17,20), AMAXSC(9,20), AMAXBC(10,20), AMAXTV(17,20), NDUMMSBCA	SBCA	11
4Y(20), IDBRTV(8,20), INBRTV(8,20), BRKTV(8,20), NDAMMY(20), WGHT(3), VOLSBCA	SBCA	12
5(3), TIME(3)	SBCA	13
3000 FORMAT(1H1, 'THE SELECTION OF T.V. NO. ', I2, ' FROM W.A. 2 MADE AT 'SBCA	SBCA	14
1, F8.1, ' UNITS OF TIME'/' AFTER THE START OF THE MISSION IS FORFEITSBCA	SBCA	15
2ED BECAUSE THERE IS NO BEACH'/' UNLOADING FACILITY AVAILABLE TO RESBCA	SBCA	16
3CEIVE IT.'/' BEACH UNLOADING FACILITY NO. ', I2, ' IS THE FIRST ONE SBCA	SBCA	17
4TO BECOME AVAILABLE AT '/1H ,F8.1, ' UNITS OF TIME AFTER THE START SBCA	SBCA	18
5OF THE MISSION.'/' THE DEPARTURE TIME OF ALL TRANSFER VEHICLES IN SBCA	SBCA	19
6W.A. 2 THAT COULD DEPART'/' BEFORE THE ABOVE CITED BEACH UNLOADINGSBCA	SBCA	20
7 FACILITY BECAME AVAILABLE IS SET'/' EQUAL TO ', F8.1, ' UNITS OF TISBCA	SBCA	21
8ME.')	SBCA	22
3100 FORMAT(1H1, 'T.V. AND BEACH UNLOADING FACILITY SELECTION.'/'/' T.V. SBCA	SBCA	23
1NO. ', I2, ' AND BEACH UNLOADING FACILITY NO. ', I2, ' ARE SELECTED AT SBCA	SBCA	24
2'/1H ,F8.1, ' AND ', F8.1, ' UNITS OF TIME AFTER THE START OF THE MISSBCA	SBCA	25
3SION'/' RESPECTIVELY.')	SBCA	26
IF(INDEX2) 100,100,1000	SBCA	27
100 L1=1	SBCA	28
IF(L-1) 1010,1010,110	SBCA	29
110 L2=2	SBCA	30
120 IF(TBCP(5,L1)-TBCP(5,L2)) 130,140,150	SBCA	31
150 L1=L2	SBCA	32
130 IF(L2-L) 160,1010,1010	SBCA	33
160 L2=L2+1	SBCA	34
GO TO 120	SBCA	35
140 IF(AMAXBC(5,L1)-AMAXBC(5,L2))130,170,150	SBCA	36

170	A1=TBC(4,L1)+TBC(6,L1)+TBC(7,L1)+TBC(8,L1)	SBCA	37
	A2=TBC(4,L2)+TBC(6,L2)+TBC(7,L2)+TBC(8,L2)	SBCA	38
	IF(A1-A2) 130,130,150	SBCA	39
1010	IF(INDEX2) 1000,195,1000	SBCA	40
195	DO 196 II=1,I	SBCA	41
	TTVP(6,II)=0.	SBCA	42
196	CONTINUE	SBCA	43
1000	IF(TBCP(5,L1)-TTVP(14,I1)) 200,200,210	SBCA	44
200	TTV(12,I1)=0.	SBCA	45
	WRITE(6,3100) I1,L1,TTVP(14,I1),TBCP(5,L1)	SBCA	46
	TTVP(14,I1)=10.**70	SBCA	47
	IDBC(5,L1)=IDBC(5,L1)+1	SBCA	48
	IDTV(8,I1)=1	SBCA	49
	INDEX2=0	SBCA	50
	GO TO 2000	SBCA	51
210	CONTINUE	SBCA	52
	WRITE(6,3000) I1,TTVP(14,I1),L1,TBCP(5,L1),TBCP(5,L1)	SBCA	53
	I1=1	SBCA	54
220	IF(IDTV(8,I1)-1) 230,230,240	SBCA	55
230	IF(I1-I) 250,260,260	SBCA	56
250	I1=I1+1	SBCA	57
	GO TO 220	SBCA	58
240	TTV(12,I1)=TBCP(5,L1)-TTVP(14,I1)	SBCA	59
	IF(TTV(12,I1)) 230,230,270	SBCA	60
270	AMAXTV(8,I1)=TBCP(5,L1)	SBCA	61
	TTVP(14,I1)=AMAXTV(8,I1)	SBCA	62
	TTVP(6,I1)=TTV(12,I1)	SBCA	63
	GO TO 230	SBCA	64
260	INDEX2=1	SBCA	65
2000	CONTINUE	SBCA	66
	RETURN	SBCA	67
	END	SBCA	68

```

SUBROUTINE SLBCR                                     SBCB  1
COMMON NCASES, NRUNS, I, K, L, N, WC, VC, TAM, T1, T2, TSC, TBC, TTV, TAMP, T1P, SBCB  2
1T2P, TSCP, TBCP, TTVP, IDMA, ID1, ID2, IDSC, IDBC, IDTV, INMS, IN1, IN2, INSC, SBCB  3
2INBC, INTV, AMINM, AMIN1, AMIN2, AMINSC, AMINBC, AMINTV, AMAXM, AMAX1, AMAX2SBCB  4
3, AMAXSC, AMAXBC, AMAXTV, ISUD, IBUD, IWA1SL, IWA2SL, ISCSL, IBCSL, INDEX1, SBCB  5
4INDEX2, I1, K1, L1, ICASE, IRUN, TTM, NDUMML, NDUMMY, WGHT, VOL, TIME, IBREAK, SBCB  6
5WT1MAX, WT2MAX, IDBRTV, INBRTV, BRKTV, NDAMMY, INDEX, ICHANG SBCB  7
DIMENSION WC(1000), VC(1000), N(20), TSC( 9,20), TBC(10,20), TTV(17,20)SBCB  8
1, TSCP( 9,20), TBCP(10,20), TTVP(17,20), IDSC( 9,20), IDBC(10,20), IDTV(SBCB  9
217,20), INSC( 9,20), INBC(10,20), INTV(17,20), AMINSC( 9,20), AMINBC(10SBCB 10
3,20), AMINTV(17,20), AMAXSC( 9,20), AMAXBC(10,20), AMAXTV(17,20), NDUMMSBCB 11
4Y(20), IDBRTV(8,20), INBRTV(8,20), BRKTV(8,20), NDAMMY(20), WGHT(3), VOLSBCB 12
5(3), TIME(3) SBCB 13
3000 FORMAT(1H1, 'THE SELECTION OF T.V. NO. ', I2, ' FROM W.A. 2 MADE AT 'SBCB 14
1, F8.1, ' UNITS OF TIME'// ' AFTER THE START OF THE MISSION IS FORFEITSBCB 15
2ED BECAUSE THERE IS NO BEACH'// ' UNLOADING FACILITY AVAILABLE TO RESBCB 16
3CEIVE IT.'// ' BEACH UNLOADING FACILITY NO. ', I2, ' IS THE FIRST ONE SBCB 17
4TO BECOME AVAILABLE AT '/1H ,F8.1, ' UNITS OF TIME AFTER THE START SBCB 18
5OF THE MISSION.'// ' THE DEPARTURE TIME OF ALL TRANSFER VEHICLES IN SBCB 19
6W.A. 2 THAT COULD DEPART'// ' BEFORE THE ABOVE CITED BEACH UNLOADINGSBCB 20
7 FACILITY BECAME AVAILABLE IS SET'// ' EQUAL TO ', F8.1, ' UNITS OF TISBCB 21
8ME.' ) SBCB 22
3100 FORMAT(1H1, 'T.V. AND BEACH UNLOADING FACILITY SELECTION.'// ' T.V. SBCB 23
1NO. ', I2, ' AND BEACH UNLOADING FACILITY NO. ', I2, ' ARE SELECTED AT SBCB 24
2'/1H ,F8.1, ' UNITS OF TIME AFTER THE START OF THE MISSION.' ) SBCB 25
3200 FORMAT(1H1, 'THE SELECTION OF BEACH UNLOADING FACILITY NO. ', I2, ' MSBCB 26
1ADE AT ', F8.1, ' UNITS'// ' OF TIME AFTER THE START OF THE MISSION ISSBCB 27
2 FORFEITED BECAUSE THERE WAS'// ' NO T.V. IN W.A. 2 TO BE SERVICED.'SBCB 28
3/' T.V. NO. ', I2, ' WILL BE THE FIRST ONE TO ARRIVE IN W.A. 2 AT ', SBCB 29
4F8.1, ' UNITS'// ' OF TIME AFTER THE START OF THE MISSION.'// ' ALL BEASBCB 30
5CH UNLOADING FACILITIES THAT ARE FREE BEFORE THE ARRIVAL OF THE'// 'SBCB 31
6 ABOVE CITED T.V. IN W.A. 2 BECOME EQUALLY ELIGIBLE FOR SELECTION.SBCB 32
7') SBCB 33
IF(INDEX2) 100,100,1000 SBCB 34
100 L1=1 SBCB 35
IF(L-1) 1010,1010,110 SBCB 36

```

110	L2=2	SBCB	37
120	IF(TBCP(5,L1)-TBCP(5,L2)) 130,140,150	SBCB	38
150	L1=L2	SBCB	39
130	IF(L2-L) 160,1010,1010	SBCB	40
160	L2=L2+1	SBCB	41
	GO TO 120	SBCB	42
140	IF(TBCP(5,L1)-AMAXBC(5,L1)) 141,143,144	SBCB	43
141	IF(TBCP(5,L2)-AMAXBC(5,L2)) 142,150,150	SBCB	44
142	IF(AMAXBC(5,L1)-AMAXBC(5,L2)) 130,170,150	SBCB	45
143	IF(TBCP(5,L2)-AMAXBC(5,L2)) 130,170,150	SBCB	46
144	IF(TBCP(5,L2)-AMAXBC(5,L2))130,130,170	SBCB	47
170	A1=TBC(4,L1)+TBC(6,L1)+TBC(7,L1)+TBC(8,L1)	SBCB	48
	A2=TBC(4,L2)+TBC(6,L2)+TBC(7,L2)+TBC(8,L2)	SBCB	49
	IF(A1-A2) 130,130,150	SBCB	50
1010	IF(INDEX2) 1000,195,1000	SBCB	51
195	DO 196 I1=1,I	SBCB	52
	TTVP(6,I1)=0.	SBCB	53
196	CONTINUE	SBCB	54
1000	IF(TBCP(5,L1)-TTVP(14,I1)) 300,200,210	SBCB	55
200	TTV(12,I1)=0.	SBCB	56
	WRITE(6,3100) I1,L1,TTVP(14,I1)	SBCB	57
	TTVP(14,I1)=10.**70	SBCB	58
	IDBC(5,L1)=IDBC(5,L1)+1	SBCB	59
	IDTV(8,I1)=1	SBCB	60
	INDEX2=0	SBCB	61
	GO TO 2000	SBCB	62
210	CONTINUE	SBCB	63
	WRITE(6,3000) I1,TTVP(14,I1),L1,TBCP(5,L1),TBCP(5,L1)	SBCB	64
	I1=1	SBCB	65
220	IF(IDTV(8,I1)-1) 230,230,240	SBCB	66
230	IF(I1-I) 250,260,260	SBCB	67
250	I1=I1+1	SBCB	68
	GO TO 220	SBCB	69
240	TTV(12,I1)=TBCP(5,L1)-TTVP(14,I1)	SBCB	70
	IF(TTV(12,I1)) 230,230,270	SBCB	71
270	AMAXTV(8,I1)=TBCP(5,L1)	SBCB	72

TTVP(14,I1)=AMAXTV(8,I1)	SBCB	73
TTVP(6,I1)=TTV(12,I1)	SBCB	74
GO TO 230	SBCB	75
260 INDEX2=1	SBCB	76
GO TO 2000	SBCB	77
300 TTV(12,I1)=0.	SBCB	78
WRITE(6,3200) L1,TBCP(5,L1),I1,TTVP(14,I1)	SBCB	79
L1=1	SBCB	80
350 IF(TBCP(5,L1)-TTVP(14,I1)) 310,320,320	SBCB	81
310 TBCP(5,L1)=TTVP(14,I1)	SBCB	82
320 IF(L1-L) 330,340,340	SBCB	83
330 L1=L1+1	SBCB	84
GO TO 350	SBCB	85
340 INDEX2=-1	SBCB	86
2000 CONTINUE	SBCB	87
RETURN	SBCB	88
END	SBCB	89

```

SUBROUTINE UNLOAD
COMMON NCASES, NRUNS, I, K, L, N, WC, VC, TAM, T1, T2, TSC, TBC, TTV, TAMP, T1P, UNLD 1
1T2P, TSCP, TBCP, TTVP, IDMA, ID1, ID2, IDSC, IDBC, IDTV, INMS, IN1, IN2, INSC, UNLD 2
2INBC, INTV, AMINM, AMIN1, AMIN2, AMINSC, AMINBC, AMINTV, AMAXM, AMAX1, AMAX2UNLD 3
3, AMAXSC, AMAXBC, AMAXTV, ISUD, IBUD, IWA1SL, IWA2SL, ISCSL, IBCSL, INDEX1, UNLD 4
4INDEX2, I1, K1, L1, ICASE, IRUN, TTM, NDUML, NDUMMY, WGHT, VOL, TIME, IBREAK, UNLD 5
5WT1MAX, WT2MAX, IDBRTV, INBRTV, BRKTV, NDAMMY, INDEX, ICHANG UNLD 6
DIMENSION WC(1000), VC(1000), N(20), TSC( 9,20), TBC(10,20), TTV(17,20)UNLD 7
1, TSCP( 9,20), TBCP(10,20), TTVP(17,20), IDSC( 9,20), IDBC(10,20), IDTV(UNLD 8
217,20), INSC( 9,20), INBC(10,20), INTV(17,20), AMINSC( 9,20), AMINBC(10UNLD 9
3,20), AMINTV(17,20), AMAXSC( 9,20), AMAXBC(10,20), AMAXTV(17,20), NDUMMUNLD 10
4Y(20), IDBRTV(8,20), INBRTV(8,20), BRKTV(8,20), NDAMMY(20), WGHT(3), VOLUNLD 11
5(3), TIME(3) UNLD 12
4000 FORMAT(1H ,///' T.V. BREAKDOWN CONSIDERATIONS.'//) UNLD 13
4001 FORMAT(' T.V. NO. ', I2, ' IS NOT ALLOWED TO DEPART W.A. 2 AS IT IS UNLD 14
1CONSIDERED TO BE'//' MALFUNCTIONING. THE ABOVE CITED T.V. AND ITS UNLD 15
2ENTIRE PAYLOAD IS'//' CONSIDERED LOST FROM OUR SYSTEM FOR THIS COMPUNLD 16
3UTER RUN. IN ADDITION THE'//' ABOVE MENTIONED T.V. AND BEACH UNLOAUNLD 17
4DING FACILITY SELECTION IS'//' FORFEITED.') UNLD 18
4002 FORMAT(' T.V. NO. ', I2, ' HAS SAFELY DEPARTED W.A. 2.') UNLD 19
4003 FORMAT(1H ,///' T.V. NO. ', I2, ' DEPARTED W.A. 2 FOR BEACH UNLOADINUNLD 20
1G AREA NO. ', I2, ', ', I, 'FR.1'//' UNITS OF TIME AFTER THE START OF THE MUNLD 21
2MISSION.') UNLD 22
4010 FORMAT(' T.V. NO. ', I2, ' IS NOT ALLOWED TO REACH THE BEACH AS IT IUNLD 23
1S CONSIDERED TO BE'//' MALFUNCTIONING. THE ABOVE CITED T.V. AND ITUNLD 24
2S ENTIRE PAYLOAD IS'//' CONSIDERED LOST FROM OUR SYSTEM FOR THIS COUNLD 25
3MPUTER RUN. IN ADDITION THE'//' ABOVE MENTIONED T.V. AND BEACH UNLUNLD 26
4ODING FACILITY SELECTION IS'//' FORFEITED.') UNLD 27
4011 FORMAT(' T.V. NO. ', I2, ' HAS SAFELY REACHED THE BEACH.') UNLD 28
4012 FORMAT(1H ,///' T.V. NO. ', I2, ' REACHED BEACH UNLOADING AREA NO. 'UNLD 29
1, I2, ' BEACHED AND WAS MADE'//' READY FOR THE UNLOADING OPERATION ', UNLD 30
2F8.1, ' UNITS OF TIME AFTER THE'//' START OF THE MISSION.') UNLD 31
4020 FORMAT(1H ,///' ALL TIME MEASURMENTS IN THE FOLLOWING TABLE HAVE ASUNLD 32
1 A COMMON DRIGIN'//' THE START OF THE MISSION.') UNLD 33
4030 FORMAT(1H ,///' OPERATION TO UNLOAD CARGO UNIT NO. ', I4//' CARGO UNUNLD 34
1IT CHARACTERISTICS:'//' WEIGHT', I4X, F5.2, I4X, '3A4'//' VOLUME', I4X, F4.0, UNLD 35

```

21X,3A4//)	UNLD	37
4040 FORMAT(' BEACH UNLOADING FACILITY (B.U.F.) OPERATION:'// ' B.U.F. REUNLD		38
1ACHES BEACH UNLOADING AREA NO. ',I2,' AFTER',2X,F8.1,1X,3A4)	UNLD	39
4050 FDMAT(' THE B.U.F. WILL COMMENCE UNLOADING AFTER',10X,F8.1,1X,3A4UNLD		40
1)	UNLD	41
4060 FORMAT(' THE ABOVE CITED CARGO UNIT IS RELEASED AFTER',6X,F8.1,1X,UNLD		42
13A4)	UNLD	43
4070 FORMAT(' IS SECURED TO THE B.U.F. AFTER',20X,F8.1,1X,3A4)	UNLD	44
4080 FORMAT(' AND IS TRANSPORTED TO THE UNLOADING ZONE AFTER',4X,F8.1,1UNLD		45
1X,3A4)	UNLD	46
4090 FORMAT(1H ,////' THE UNLOADING OPERATION IS TERMINATED AS THE ENTIUNLD		47
1RE PAYLOAD OF T.V.'// ' NO. ',I2,' HAS BEEN OFFLOADED.'////' T.V. NOUNLD		48
2. ',I2,' WAS READY TO DEPART FROM THE BEACH ',F8.1,' UNITS OF TIMEUNLD		49
3'// ' AFTER THE START OF THE MISSION')	UNLD	50
4100 FORMAT(' AND AT THE SAME TIME BEACH UNLOADING AREA NO. ',I2,' BECAUNLD		51
1MF ONCE MORE'// ' AVAILABLE.')	UNLD	52
4110 FORMAT(' AND AT THE SAME TIME ALL BEACH UNLOADING AREAS BECAME ONCUNLD		53
1E MORE'// ' AVAILABLE.')	UNLD	54
4120 FORMAT(1H ,////' FOR ANALYSIS PURPOSES T.V. NO. ',I2,' IS ASSUMED UNLD		55
1TO PROCEED FOR W.A. 1.'// ' HOWEVER, IF AT THE TERMINATION OF THIS RUNLD		56
2UN IT IS FOUND THAT THE ABOVE'// ' CITED T.V. COULD PROCEED DIRECTLYUNLD		57
3 TO ITS BASE (FROM BEACH UNLOADING'// ' AREA NO. ',I2,') WITHOUT DELUNLD		58
4AYING THE MISSION ALL DECISIONS MADE AT THIS'// ' STAGE WILL BE FORFUNLD		59
5FITED, AND THE ABOVE CITED T.V. WILL PROCEED DIRECTLY'// ' TO ITS BAUNLD		60
6SE.')	UNLD	61
4130 FORMAT(1H , 'T.V. NO. ',I2,' IS NOT ALLOWED TO ENTER W.A. 1 AS IT UNLD		62
1IS CONSIDERED TO BE'// ' MALFUNCTIONING. THE ABOVE CITED T.V. IS (WUNLD		63
2ITH THE ABOVE PROVISION)'// ' CONSIDERED LOST FROM OUR SYSTEM FOR THUNLD		64
3IS COMPUTER RUN.')	UNLD	65
4140 FORMAT(' T.V. NO. ',I2,' HAS SAFELY ENTERED W.A. 1.')	UNLD	66
4150 FORMAT(1H ,////' T.V. NO. ',I2,' ARRIVED AT W.A. 1 ',F8.1,' UNITS UNLD		67
1OF TIME AFTER THE START OF'// ' THE MISSION.')	UNLD	68
4160 FORMAT(1H ,////' SINCE THE ENTIRE MOTHER SHIP',1H', 'S PAYLOAD HAS UNLD		69
1BEEN OFFLOADED INTO TRANSFER'// ' VEHICLES THE ABOVE CITED T.V. WILUNLD		70
2L PROCEED DIRECTLY TO ITS BASE.')	UNLD	71
DO 100 JJ=12,13	UNLD	72

IDD=IDTV(JJ,I1)	UNLD	73
GO TO (2000,2001),IDD	UNLD	74
2000 TTVP(JJ,I1)=0.	UNLD	75
GO TO 100	UNLD	76
2001 IND=IDTV(JJ,I1)	UNLD	77
CALL RANDU(IND,IND,TPD)	UNLD	78
INTV(JJ,I1)=IND	UNLD	79
TTVP(JJ,I1)=(AMAXTV(JJ,I1)-AMINTV(JJ,I1))*TPD+AMINTV(JJ,I1)-TTV(JJ,I1)	UNLD	80
1,I1)	UNLD	81
GO TO 100	UNLD	82
100 CONTINUE	UNLD	83
IDD=IDBRTV(5,I1)	UNLD	84
GO TO (3000,3001),IDD	UNLD	85
3001 TTVP(6,I1)=TTVP(6,I1)+TTVP(12,I1)	UNLD	86
TTVP(6,I1)=TTVP(6,I1)/WT1MAX	UNLD	87
IF(TTVP(6,I1)-1.) 3002,3003,3003	UNLD	88
3002 TTVP(6,I1)=TTVP(6,I1)*BRKTV(5,I1)	UNLD	89
GO TO 3004	UNLD	90
3003 TTVP(6,I1)=BRKTV(5,I1)	UNLD	91
3004 IND=INBRTV(5,I1)	UNLD	92
CALL RANDU(IND,IND,TPD)	UNLD	93
INBRTV(5,I1)=IND	UNLD	94
IF(TTVP(6,I1)-TPD) 3005,3005,3006	UNLD	95
3006 IDTV(14,I1)=IDTV(14,I1)-1	UNLD	96
IDTV(8,I1)=0	UNLD	97
IBREAK=IBREAK-1	UNLD	98
IDBC(5,L1)=IDBC(5,L1)-1	UNLD	99
WRITE(6,4000)	UNLD	100
WRITE(6,4001) I1	UNLD	101
GO TO 3007	UNLD	102
3005 CONTINUE	UNLD	103
WRITE(6,4000)	UNLD	104
WRITE(6,4002) I1	UNLD	105
3000 CONTINUE	UNLD	106
AMAXTV(8,I1)=AMAXTV(8,I1)+TTV(12,I1)+TTVP(12,I1)	UNLD	107
WRITE(6,4003) I1,L1,AMAXTV(8,I1)	UNLD	108

	IDD=IDBRTV(6,I1)	UNLD 109
	GO TO (3008,3009),IDD	UNLD 110
3009	IND=INBRTV(6,I1)	UNLD 111
	CALL RANDU(IND,IND,TPD)	UNLD 112
	INBRTV(6,I1)=IND	UNLD 113
	IF(BRKTV(6,I1)-TPD) 3011,3011,3012	UNLD 114
3012	IDTV(14,I1)=IDTV(14,I1)-1	UNLD 115
	IDTV(8,I1)=0	UNLD 116
	IBREAK=IBREAK-1	UNLD 117
	IDBC(5,L1)=IDBC(5,L1)-1	UNLD 118
	WRITE(6,4000)	UNLD 119
	WRITE(6,4010) I1	UNLD 120
	GO TO 3007	UNLD 121
3011	CONTINUE	UNLD 122
	WRITE(6,4000)	UNLD 123
	WRITE(6,4011) I1	UNLD 124
3008	CONTINUE	UNLD 125
	AMAXTV(8,I1)=AMAXTV(8,I1)+TTV(13,I1)+TTVP(13,I1)	UNLD 126
	WRITE(6,4012) I1,L1,AMAXTV(8,I1)	UNLD 127
	WRITE(6,4020)	UNLD 128
	NTEMP=NDAMMY(I1)	UNLD 129
1200	IDD=IDBC(4,L1)	UNLD 130
	GO TO (2010,2011),IDD	UNLD 131
2010	TBCP(4,L1)=0.	UNLD 132
	GO TO 3010	UNLD 133
2011	IND=INBC(4,L1)	UNLD 134
	CALL RANDU(IND,IND,TPD)	UNLD 135
	INBC(4,L1)=IND	UNLD 136
	TBCP(4,L1)=(AMAXBC(4,L1)-AMINBC(4,L1))*TPD+AMINBC(4,L1)-TBC(4,L1)	UNLD 137
	GO TO 3010	UNLD 138
3010	AMAXBC(5,L1)=AMAXBC(5,L1)+TBC(4,L1)+TBCP(4,L1)	UNLD 139
	WRITE(6,4030) NTEMP,WC(NTEMP),(WGHT(JJ),JJ=1,3),VC(NTEMP),(VOL(JJ)	UNLD 140
	1, JJ=1,3)	UNLD 141
	WRITE(6,4040) L1,AMAXBC(5,L1),(TIME(JJ),JJ=1,3)	UNLD 142
	IF(AMAXBC(5,L1)-AMAXTV(8,I1)) 1000,1000,1100	UNLD 143
1000	TTV(14,I1)=0.	UNLD 144

	TBC(5,L1)=AMAXTV(8,I1)-AMAXBC(5,L1)	UNLD 145
	GO TO 1010	UNLD 146
1100	TTV(14,I1)=AMAXBC(5,L1)-AMAXTV(8,I1)	UNLD 147
	TBC(5,L1)=0.	UNLD 148
1010	AMAXTV(8,I1)=AMAXTV(8,I1)+TTV(14,I1)	UNLD 149
	AMAXBC(5,L1)=AMAXBC(5,L1)+TBC(5,L1)	UNLD 150
	WRITE(6,4050) AMAXBC(5,L1),(TIME(JJ),JJ=1,3)	UNLD 151
	DO 110 JJ=6,8	UNLD 152
	IDD=IDBC(JJ,L1)	UNLD 153
	GO TO (2020,2021),IDD	UNLD 154
2020	TBCP(JJ,L1)=0.	UNLD 155
	GO TO 110	UNLD 156
2021	IND=INBC(JJ,L1)	UNLD 157
	CALL RANDU(IND,IND,TPD)	UNLD 158
	INBC(JJ,L1)=IND	UNLD 159
	TBCP(JJ,L1)=(AMAXBC(JJ,L1)-AMINBC(JJ,L1))*TPD+AMINBC(JJ,L1)-TBC(JJ,UNLD 160	
	1,L1)	UNLD 161
	GO TO 110	UNLD 162
110	CONTINUE	UNLD 163
	AMAXTV(8,I1)=AMAXTV(8,I1)+TBC(6,L1)+TBCP(6,L1)	UNLD 164
	AMAXBC(5,L1)=AMAXBC(5,L1)+TBC(6,L1)+TBCP(6,L1)	UNLD 165
	WRITE(6,4060) AMAXBC(5,L1),(TIME(JJ),JJ=1,3)	UNLD 166
	AMAXTV(8,I1)=AMAXTV(8,I1)+TBC(7,L1)+TBCP(7,L1)	UNLD 167
	AMAXBC(5,L1)=AMAXBC(5,L1)+TBC(7,L1)+TBCP(7,L1)	UNLD 168
	WRITE(6,4070) AMAXBC(5,L1),(TIME(JJ),JJ=1,3)	UNLD 169
	AMAXBC(5,L1)=AMAXBC(5,L1)+TBC(8,L1)+TBCP(8,L1)	UNLD 170
	WRITE(6,4080) AMAXBC(5,L1),(TIME(JJ),JJ=1,3)	UNLD 171
	NTEMP=NTEMP+1	UNLD 172
	IF(NDUMMY(I1)-NTEMP) 1300,1200,1200	UNLD 173
1300	DO 120 JJ=15,16	UNLD 174
	IDD=IDTV(JJ,I1)	UNLD 175
	GO TO (2040,2041),IDD	UNLD 176
2040	TTVP(JJ,I1)=0.	UNLD 177
	GO TO 120	UNLD 178
2041	IND=INTV(JJ,I1)	UNLD 179
	CALL RANDU(IND,IND,TPD)	UNLD 180

INTV(JJ,I1)=IND	UNLD 181
TTVP(JJ,I1)=(AMAXTV(JJ,I1)-AMINTV(JJ,I1))*TPD+AMINTV(JJ,I1)-TTV(JJ,I1)	UNLD 182
GO TO 120	UNLD 183
120 CONTINUE	UNLD 184
AMAXTV(8,I1)=AMAXTV(8,I1)+TTV(15,I1)+TTVP(15,I1)	UNLD 185
AMAXTV(14,I1)=AMAXTV(8,I1)	UNLD 186
WRITE(6,4090) I1,I1,AMAXTV(8,I1)	UNLD 187
IF(IBUD-1) 1400,1500,1400	UNLD 188
1400 LLOOP=L	UNLD 189
LT=1	UNLD 190
WRITE(6,4110)	UNLD 191
GO TO 1410	UNLD 192
1500 LLOOP=1	UNLD 193
LT=L1	UNLD 194
WRITE(6,4100) L1	UNLD 195
1410 DO 130 LL=1,LLOOP	UNLD 196
TBCP(5,LT)=AMAXTV(14,I1)	UNLD 197
LT=LT+1	UNLD 198
130 CONTINUE	UNLD 199
IF(INDEX) 1600,1600,1601	UNLD 200
1601 IDTV(8,I1)=-1	UNLD 201
WRITE(6,4160)	UNLD 202
GO TO 3007	UNLD 203
1600 CONTINUE	UNLD 204
WRITE(6,4120) I1,L1	UNLD 205
IDD=IDBRTV(7,I1)	UNLD 206
GO TO (3100,3101),IDD	UNLD 207
3101 IND=INBRTV(7,I1)	UNLD 208
CALL RANDU(IND,IND,TPD)	UNLD 209
INBRTV(7,I1)=IND	UNLD 210
IF(BRKTV(7,I1)-TPD) 3110,3110,3111	UNLD 211
3111 IDTV(14,I1)=IDTV(14,I1)-1	UNLD 212
INTV(14,I1)=-1	UNLD 213
IBREAK=IBREAK-1	UNLD 214
WRITE(6,4000)	UNLD 215
	UNLD 216

WRITE(6,4130) I1	UNLD 217
GO TO 3100	UNLD 218
3110 CONTINUE	UNLD 219
WRITE(6,4000)	UNLD 220
WRITE(6,4140) I1	UNLD 221
3100 AMAXTV(8,I1)=AMAXTV(8,I1)+TTV(16,I1)+TTVP(16,I1)	UNLD 222
TTVP(8,I1)=AMAXTV(8,I1)	UNLD 223
WRITE(6,4150) I1,AMAXTV(8,I1)	UNLD 224
3007 CONTINUE	UNLD 225
RETURN	UNLD 226
END	UNLD 227

```

SUBROUTINE FIN
COMMON NCASES, NRUNS, I, K, L, N, WC, VC, TAM, T1, T2, TSC, TBC, TTV, TAMP, T1P, SFIN 1
1T2P, TSCP, TBCP, TTVP, IDMA, ID1, ID2, IDSC, IDBC, IDTV, INMS, IN1, IN2, INSC, SFIN 2
2INBC, INTV, AMINM, AMIN1, AMIN2, AMINSC, AMINBC, AMINTV, AMAXM, AMAX1, AMAX2 SFIN 3
3, AMAXSC, AMAXBC, AMAXTV, ISUD, IBUD, IWA1SL, IWA2SL, ICSL, IBCSL, INDEX1, SFIN 4
4INDEX2, I1, K1, L1, ICASE, IRUN, TTM, NDUML, NDUMMY, WGHT, VOL, TIME, IBREAK, SFIN 5
5WT1MAX, WT2MAX, IDBRTV, INBRTV, BRKTV, NDAMMY, INDEX, ICHANG SFIN 6
DIMENSION WC(1000), VC(1000), N(20), TSC( 9,20), TBC(10,20), TTV(17,20) SFIN 7
1, TSCP( 9,20), TBCP(10,20), TTVP(17,20), IDSC( 9,20), IDBC(10,20), IDTV(SFIN 8
217,20), INSC( 9,20), INBC(10,20), INTV(17,20), AMINSC( 9,20), AMINBC(10 SFIN 9
3,20), AMINTV(17,20), AMAXSC( 9,20), AMAXBC(10,20), AMAXTV(17,20), NDUMMSFIN 10
4Y(20), IDBRTV(8,20), INBRTV(8,20), BRKTV(8,20), NDAMMY(20), WGHT(3), VOL SFIN 11
5(3), TIME(3) SFIN 12
4000 FORMAT(1H1, 'WITH THE OPERATION JUST DESCRIBED THE TRANSFER OF THE SFIN 13
1ENTIRE MOTHER'// 'SHIP', 1H', 'S PAYLOAD INTO TRANSFER VEHICLES WAS CSFIN 14
2COMPLETED. THEREFORE, IN'// ' ORDER TO COMPLETE THE TRANSFER MISSIONSFIN 15
3 WE ONLY NEED TO TRANSPORT THE'// ' CARGO AWAITING IN, OR ON ROUTE TSFIN 16
40, W.A. 2, TO ITS DESTINATION. THIS'// ' OPERATION IS DESCRIBED IN SFIN 17
5THE FOLLOWING PAGES.') SFIN 18
4010 FORMAT(1H1, 'WITH THE OPERATION JUST DESCRIBED THE TRANSFER MISSIOSFIN 19
1N IS COMPLETED.'// ' THE QUANTITIES THAT WILL BE CALCULATED IN WHAT SFIN 20
2FOLLOWS ARE NECESSARY'// ' FOR THE STATISTICAL ANALYSIS.'//'/') SFIN 21
4020 FORMAT(' MOTHER SHIP', 1H', 'S DEPARTURE OPERATION.'// ' THE DEPARTURSFIN 22
1E OPERATION FOR THE MOTHER SHIP COMMENCED ', F8.1// ' UNITS OF TIME ASFIN 23
2FTER THE START OF THE MISSION AND WAS COMPLETED') SFIN 24
4030 FORMAT(1H ,F8.1, ' OF TIME AFTER THE START OF THE MISSION.') SFIN 25
4040 FORMAT(1H1, 'DEPARTURE OF BEACH BASED UNLOADING FACILITIES (B.U.F.) SFIN 26
1.'//'/') SFIN 27
4050 FORMAT(' B.U.F. NO. ', I2, ' CAN BE REMOVED FROM OUR SYSTEM AS IT HASFIN 28
1S NOT BEEN USED.') SFIN 29
4060 FORMAT(' B.U.F. NO. ', I2, ' WAS READY TO DEPART THE UNLOADING ZONE SFIN 30
1', F8.1, ' UNITS OF'// ' TIME AFTER THE START OF THE MISSION AND ARRIVSFIN 31
2ED AT ITS DESTINATION') SFIN 32
4070 FORMAT(1H ,F8.1, ' UNITS OF TIME AFTER THE START OF THE MISSION.'//) SFIN 33
4080 FORMAT(1H1, 'DEPARTURE OF TRANSFER VEHICLES.'//'/') SFIN 34
4090 FORMAT(' T.V. NO. ', I2, ' HAS BEEN REMOVED FROM OUR SYSTEM AS IT WASFIN 35

```

1S MALFUNCTIONING.'//)	SFIN	37
4100 FORMAT(' T.V. NO. ',I2,' CAN BE REMOVED FROM OUR SYSTEM AS IT HAS	SFIN	38
1NOT BEEN USED. (FORFEIT'/' PREVIOUS DECISION CONCERNING T.V. NO.	SFIN	39
2',I2,2H.)//)	SFIN	40
4110 FORMAT(' T.V. NO. ',I2,' CAN BE REMOVED FROM OUR SYSTEM AS IT HAS	SFIN	41
1NOT BEEN USED. (FORFEIT'/' PREVIOUS DECISION AND MALFUNCTIONING CSFIN	SFIN	42
2CONSIDERATIONS CONCERNING T.V.'/' NO. ',I2,2H.)//)	SFIN	43
4120 FORMAT(' T.V. NO. ',I2,' DEPARTED THE BEACH UNLOADING AREA ',F8.1,SFIN	SFIN	44
1' UNITS OF TIME'/' AFTER THE START OF THE MISSION.')	SFIN	45
4130 FORMAT(' BREAKDOWN CONSIDERATIONS.')	SFIN	46
4140 FORMAT(' T.V. NO. ',I2,' DID NOT REACH ITS BASE AS IT MALFUNCTIONESFIN	SFIN	47
1D ON ROUTE.'//)	SFIN	48
4150 FORMAT(' T.V. NO. ',I2,' ARRIVED SAFELY AT ITS BASE ',F8.1,' UNITSSFIN	SFIN	49
1 OF TIME AFTER THE'/' START OF THE MISSION.'//)	SFIN	50
4160 FORMAT(' (FORFEIT PREVIOUS DECISION CONCERNING T.V. NO. ',I2,1H))	SFIN	51
INDEX=1	SFIN	52
4170 FORMAT(' (FORFEIT PREVIOUS DECISION AND MALFUNCTIONING CONSIDERATISFIN	SFIN	53
1ONS CONCERNING'/' T.V. NO. ',I2,1H))	SFIN	54
WRITE(6,4000)	SFIN	55
1100 I1=1	SFIN	56
TDMMY=TTVP(8,1)	SFIN	57
TTVP(8,1)=10.**70	SFIN	58
GO TO (1001,1002,1003,1004),IWA2SL	SFIN	59
1001 CONTINUE	SFIN	60
CALL BSLTVA	SFIN	61
CONTINUE	SFIN	62
GO TO 1000	SFIN	63
1002 CONTINUE	SFIN	64
CALL BSLTVB	SFIN	65
CONTINUE	SFIN	66
GO TO 1000	SFIN	67
1003 CONTINUE	SFIN	68
CALL BSLTVC	SFIN	69
CONTINUE	SFIN	70
GO TO 1000	SFIN	71
1004 CONTINUE	SFIN	72

CALL BSLTV0	SFIN 73
CONTINUE	SFIN 74
GO TO 1000	SFIN 75
1000 TTVP(8,1)=TDMMY	SFIN 76
GO TO (1011,1012),IBCSL	SFIN 77
1011 CONTINUE	SFIN 78
CALL SLBCA	SFIN 79
CONTINUE	SFIN 80
GO TO 1010	SFIN 81
1012 CONTINUE	SFIN 82
CALL SLBCB	SFIN 83
CONTINUE	SFIN 84
GO TO 1010	SFIN 85
1010 IF (INDEX2) 1000,1020,1100	SFIN 86
1020 CONTINUE	SFIN 87
CALL UNLJAD	SFIN 88
DO 100 II=1,I	SFIN 89
IF(IDTV(8,II)-1) 100,100,1100	SFIN 90
100 CONTINUE	SFIN 91
WRITE(6,4010)	SFIN 92
1200 KE1=1	SFIN 93
KE2=1	SFIN 94
IF(K-1) 1210,1211,1210	SFIN 95
1210 KF=2	SFIN 96
1250 IF(AMAXSC(6,KE1)-AMAXSC(6,KF)) 1220,1230,1230	SFIN 97
1220 KE1=KF	SFIN 98
1230 IF(TSCP(6,KE2)-TSCP(6,KF))1221,1231,1221	SFIN 99
1221 KE2=KF	SFIN 100
1231 IF(KF-K) 1240,1211,1211	SFIN 101
1240 KF=KF+1	SFIN 102
GO TO 1250	SFIN 103
1211 CONTINUE	SFIN 104
GO TO (1261,1262),ID2	SFIN 105
1261 T2P=0.	SFIN 106
GO TO 1260	SFIN 107
1262 CONTINUE	SFIN 108

CALL RANDU(IN2,IN2,T2P)	SFIN 109
T2P=(AMAX2-AMIN2)*T2P+AMIN2-T2	SFIN 110
GO TO 1260	SFIN 111
1260 IF(AMAXSC(6,KE1)-TSCP(6,KE2)) 1271,1271,1272	SFIN 112
1271 TTM=TSCP(6,KE2)+T2+T2P	SFIN 113
WRITE(6,4020) TSCP(6,KE2)	SFIN 114
GO TO 1270	SFIN 115
1272 TTM=AMAXSC(6,KE1)+T2+T2P	SFIN 116
WRITE(6,4020) AMAXSC(6,KE1)	SFIN 117
1270 CONTINUE	SFIN 118
WRITE(6,4030) TTM	SFIN 119
WRITE(6,4040)	SFIN 120
DO 110 LL=1,L	SFIN 121
IF(IDBC(5,LL)) 1300,1310,1300	SFIN 122
1310 AMAXBC(5,LL)=0.	SFIN 123
WRITE(6,4050) LL	SFIN 124
GO TO 110	SFIN 125
1300 DO 120 JJ=9,10	SFIN 126
IDD=IDBC(JJ,LL)	SFIN 127
GO TO (1321,1322),IDD	SFIN 128
1321 TBCP(JJ,LL)=0.	SFIN 129
GO TO 120	SFIN 130
1322 IND=INBC(JJ,LL)	SFIN 131
CALL RANDU(IND,IND,TPD)	SFIN 132
INBC(JJ,LL)=IND	SFIN 133
TBCP(JJ,LL)=(AMAXBC(JJ,LL)-AMINBC(JJ,LL))*TPD+AMINBC(JJ,LL)-TBC(JJ,	SFIN 134
1,LL)	SFIN 135
GO TO 120	SFIN 136
120 CONTINUE	SFIN 137
AMAXBC(5,LL)=AMAXBC(5,LL)+TBC(9,LL)+TBCP(9,LL)	SFIN 138
WRITE(6,4060) LL,AMAXBC(5,LL)	SFIN 139
AMAXBC(5,LL)=AMAXBC(5,LL)+TBC(10,LL)+TBCP(10,LL)	SFIN 140
WRITE(6,4070) AMAXBC(5,LL)	SFIN 141
110 CONTINUE	SFIN 142
WRITE(6,4080)	SFIN 143
DO 130 II=1,I	SFIN 144

	IF(IDTV(8,II)) 1401,1402,1403	SFIN 145
1401	CONTINUE	SFIN 146
	WRITE(6,4120) II,AMAXTV(14,II)	SFIN 147
1410	IDD=IDTV(17,II)	SFIN 148
	GO TO (2001,2002),IDD	SFIN 149
2001	TTVP(17,II)=0.	SFIN 150
	GO TO 2000	SFIN 151
2002	IND=INTV(17,II)	SFIN 152
	CALL RANDU(IND,IND,TPD)	SFIN 153
	INTV(17,II)=IND	SFIN 154
	TTVP(17,II)=(AMAXTV(17,II)-AMINTV(17,II))*TPD+AMINTV(17,II)-TTV(17,II)	SFIN 155
	GO TO 2000	SFIN 156
2000	IDD=IDBRTV(8,II)	SFIN 157
	GO TO (2011,2012),IDD	SFIN 158
2012	IND=INBRTV(8,II)	SFIN 159
	CALL RANDU(IND,IND,TPD)	SFIN 160
	INBRTV(8,II)=IND	SFIN 161
	IF(BRKTV(8,II)-TPD) 2013,2013,2014	SFIN 162
2014	IBREAK=IBREAK-1	SFIN 163
	WRITE(6,4130)	SFIN 164
	WRITE(6,4140) II	SFIN 165
	GO TO 130	SFIN 166
2013	CONTINUE	SFIN 167
	WRITE(6,4130)	SFIN 168
2011	AMAXTV(8,II)=AMAXTV(14,II)+TTV(17,II)+TTVP(17,II)	SFIN 169
	WRITE(6,4150) II,AMAXTV(8,II)	SFIN 170
	GO TO 130	SFIN 171
1402	CONTINUE	SFIN 172
	WRITE(6,4090) II	SFIN 173
	GO TO 130	SFIN 174
1403	IF(INTV(14,II)) 1411,1412,1413	SFIN 175
1411	IDTV(14,II)=IDTV(14,II)+1	SFIN 176
	IBREAK=IBREAK+1	SFIN 177
	WRITE(6,4120) II,AMAXTV(14,II)	SFIN 178
	WRITE(6,4170) II	SFIN 179
		SFIN 180

```
      GO TO 1410
1413 IBREAK=IBREAK+1
      WRITE (6,4110) II,II
      GO TO 130
1412 IF(IDTV(14,II))1420,1420,1421
1420 WRITE (6,4100) II,II
      GO TO 130
1421 CONTINUE
      WRITE (6,4120) II,AMAXTV(14,II)
      WRITE (6,4160) II
      GO TO 1410
130  CONTINUE
      RETURN
      END
```

```
SFIN 181
SFIN 182
SFIN 183
SFIN 184
SFIN 185
SFIN 186
SFIN 187
SFIN 188
SFIN 189
SFIN 190
SFIN 191
SFIN 192
SFIN 193
SFIN 194
```

```
SUBROUTINE RANDU(IX,IY,YFL)
  IY=IX*65539
  IF(IY) 5,6,6
5  IY=IY+2147483647+1
6  YFL=IY
  YFL=YFL*.4656613E-9
  RETURN
END
```

```
RAND 1
RAND 2
RAND 3
RAND 4
RAND 5
RAND 6
RAND 7
RAND 8
```

```
SUBROUTINE RANDU(IX,IY,YFL)
  IY=IX*65539
  IF(IY) 5,6,6
5  IY=IY+2147483647+1
6  YFL=IY
  YFL=YFL*.4656613E-9
  YFL=1.-YFL
  RETURN
  END
```

```
RXMD 1
RXMD 2
RXMD 3
RXMD 4
RXMD 5
RXMD 6
RXMD 7
RXMD 8
RXMD 9
```

	DIMENSION X(500,8),Y(500,8),XM(8),YM(8),XV(8),YV(8),XC(8)	STAT	1
1000	FORMAT(I4)	STAT	2
1100	FORMAT(8(F8.1,1X))	STAT	3
1200	FORMAT(1H1,1H , 'MEAN AND VARIANCE CALCULATIONS'////)	STAT	4
1300	FORMAT(1H , 'VARIABLE NO. ',I1/1H , 'U(A,B) ',25X, '1-U(A,B)'/1H , 'MEASTAT	5	
	1N=',4X,F15.6,5X, 'MEAN=',4X,F15.6/1H , 'VARIANCE=',F15.6,5X, 'VARIANCSTAT	6	
	2F=',F15.6/)	STAT	7
1400	FORMAT(1H1,1H , 'MEAN COVARIANCE VARIANCE AND EFFICIENCY CALCULATIOSTAT	8	
	INS'////)	STAT	9
1500	FORMAT(1H , 'VARIABLE NO. ',I1/1H , 'MEAN=',6X,F15.6,5X, 'COVARIANCE=STAT	10	
	1',F15.6,5X, 'VARIANCE=',2X,F15.6,5X, 'EFFICIENCY=',F15.6/)	STAT	11
	READ(5,1000) KASES	STAT	12
	READ(5,1000) NRUNS	STAT	13
	READ(5,1000) IVARS	STAT	14
	DO 100 K=1,KASES	STAT	15
	DO 200 N=1,NRUNS	STAT	16
	READ(5,1100) (X(N,I),I=1,IVARS)	STAT	17
200	CONTINUE	STAT	18
	DO 300 N=1,NRUNS	STAT	19
	READ(5,1100) (Y(N,I),I=1,IVARS)	STAT	20
300	CONTINUE	STAT	21
	DO 400 I=1,IVARS	STAT	22
	XM(I)=0.	STAT	23
	YM(I)=0.	STAT	24
	XV(I)=0.	STAT	25
	YV(I)=0.	STAT	26
400	CONTINUE	STAT	27
	DO 500 N=1,NRUNS	STAT	28
	DO 600 I=1,IVARS	STAT	29
	XM(I)=XM(I)+X(N,I)	STAT	30
	YM(I)=YM(I)+Y(N,I)	STAT	31
600	CONTINUE	STAT	32
500	CONTINUE	STAT	33
	RUNS=NRUNS	STAT	34
	DO 700 I=1,IVARS	STAT	35
	XM(I)=XM(I)/RUNS	STAT	36

	YM(I)=YM(I)/RUNS	STAT	37
700	CONTINUE	STAT	38
	DO 800 N=1, NRUNS	STAT	39
	DO 900 I=1, IVARS	STAT	40
	XV(I)=XV(I)+(X(N,I)-XM(I))**2	STAT	41
	YV(I)=YV(I)+(Y(N,I)-YM(I))**2	STAT	42
900	CONTINUE	STAT	43
800	CONTINUE	STAT	44
	WRITE(6,1200)	STAT	45
	DO 2000 I=1, IVARS	STAT	46
	XV(I)=XV(I)/(RUNS-1.)	STAT	47
	YV(I)=YV(I)/(RUNS-1.)	STAT	48
	WRITE(6,1300) I,XM(I),YM(I),XV(I),YV(I)	STAT	49
2000	CONTINUE	STAT	50
	DO 2100 I=1, IVARS	STAT	51
	XC(I)=0.	STAT	52
2100	CONTINUE	STAT	53
	DO 2200 N=1, NRUNS	STAT	54
	DO 2300 I=1, IVARS	STAT	55
	XC(I)=XC(I)+(X(N,I)-XM(I))*(Y(N,I)-YM(I))	STAT	56
2300	CONTINUE	STAT	57
2200	CONTINUE	STAT	58
	WRITE(6,1400)	STAT	59
	DO 2400 I=1, IVARS	STAT	60
	XM(I)=(XM(I)+YM(I))*0.5	STAT	61
	XC(I)=XC(I)/RUNS	STAT	62
	YM(I)=XV(I)+YV(I)	STAT	63
	XV(I)=YM(I)+(2.*RUNS*XC(I))/(RUNS-1.)	STAT	64
	YV(I)=XV(I)*0.25	STAT	65
	XV(I)=YM(I)/XV(I)	STAT	66
	WRITE(6,1500) I,XM(I),XC(I),YV(I),XV(I)	STAT	67
2400	CONTINUE	STAT	68
100	CONTINUE	STAT	69
	END	STAT	70

The author was born in Alexandria, Egypt, on October 27, 1942, where he attended the Greek public schools from 1948 to 1960. In the years 1960 and 1961 he attended the Percival Whitley College in Halifax, England, where he obtained his A levels and in the years 1961 - 1965 he attended the University of Newcastle upon Tyne, England (then known as Kings College, University of Durham) where he received his B.Sc. with honours in Naval Architecture. Since 1965 the author has been residing in Cambridge, Massachusetts while attending the Massachusetts Institute of Technology, where he received his M.S. in 1967, his Engineer's (Nav. Arch.) degree in 1968 and in 1970 completed his thesis for the degree for the Doctor of Philosophy in ship systems analysis (Department of Naval Architecture and Marine Engineering).

The author has taught in the Department of Naval Architecture and Marine Engineering on the subject of ship design (1965-1969).

The title of the publication which is directly related to this thesis is "Ship-to-Shore Interface Analysis" 1969, M.I.T., Department of Naval Architecture and Marine Engineering Report No. 69-8.

Professional experience includes working in European shipyards in 1961-1963 and consulting for several companies in the U.S.A. in 1965-1968.